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WAYS TO COMFORTABLE LIGHTING

by L. C. KALFF.

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By its basic problem and by the way the solution of this problem is approached this article is characteristic of the personality of the writer, much more so than are most other articles published in this Review. Ir. Kalff, who is well known in many countries for his achievements in architectural and exhibition lighting etc., has propounded at several international meetings in the past year the views expressed in this article. The editors feel that these views, balancing on (or trespassing beyond) the borderline between science and art, may be of interest to the layman as well as to the expert in the lighting field.

The problem of comfortable lighting

Up to 1910-1920 it was usual to have in our houses rather dark walls and ceilings. Artificial lighting was, in comparison to what we have now, scarce and for that reason could only be used as local lighting. A lamp over the table, a reading lamp, wall brackets near the fireplace could spread only small circles of light.

Gradually the output of electric lamps increased. Electric current prices went down and light became cheaper. From 1915-1925 the first general lighting systems appeared in offices and factories. It is true that the levels used then would now be considered much too low (4 to 6 lm/sq.ft). In those days we find the tendency to use white ceilings and light colours for walls and furniture. This trend had been advertised not only by decorators but it was also warmly supported by lighting men who stressed the point of efficiency.

Gradually this vogue to have light colours in interiors became more and more general in Europe and in America. After a while, however, it was found that high level installations (e.g. 50 lm/sq.ft) did not give satisfactory results in these light coloured interiors. This fact was put forth in 1937 by Ward Harrison of Cleveland in his remarkable article¹⁾: "What is wrong with our fifty-footcandle installa-

tions?" The question was answered by the observation that in many high level installations glare or a feeling of discomfort is caused by the light sources, or that the attention is distracted by an unsuitable distribution of brightnesses in the visual field. A new conception, called "Brightness Engineering", was to direct the activity of the lighting engineer. This conception gained even more importance by the advent of the fluorescent lamps with their high efficiency, causing a very rapid development in lighting technique and lighting levels since 1945.

The aim of the conception of Brightness Engineering was mainly in the negative: discomfort had to be avoided. The following theories aim at making possible a positive approach to the problem. It is not enough to avoid discomfort but we should endeavour by careful planning to create comfort. It will be made clear in this article that this setting of the task should lead to closer co-operation of the lighting expert with the creative artist, architect and decorator, as we will have to go back to darker and coloured walls and ceilings in order to obtain similar comfort and atmosphere to that which we had before, with the lower level installations.

Such a co-operation will perhaps not easily be established. Up to now co-operation between the two groups has been an almost completely one-way

¹⁾ W. Harrison, Ill. Eng. 32, 208, 1937.

traffic. Lighting men were trying to induce the artist into including light in his decorations, so as to obtain a certain lighting level, avoiding discomfort from glare, shadows or reflections. The artist has been reluctant to respond to these efforts, for various reasons. Obviously he does not like to complicate still more his work which is already tremendously complicated with modern techniques and constructions. Further, the methods and instruments offered to him by the lighting expert, useful though they may be in the hands of the latter, are mostly very unhandy tools in the hands of the creative artist. But above all, the artist rightly must have assessed the tools given to him by the lighting expert as inadequate for his aims. In fact, for the architect — and really for everybody — the calculations of brightness and brightness ratios and also of glare are of a very limited value, since these calculations can only be made after conception of an interior. In the activity of the creative artist they can furnish a check but no guiding indications in what direction to think.

There seems to be only one way to improve this situation: only when the artist feels that he can handle light in much the same way as he can handle colours, shapes and materials, will the lighting problem cease to be a nuisance to him. He will feel able to master the problem of seeing-comfort as soon as this will have become part of his natural activities. In order to favour this development the lighting expert should take a completely new attitude towards the study of lighting. He should try to understand the problems of the artist and consider the way in which a lighting system together with the decorator's shaping of a room can provide seeing-comfort.

This is the basic trend of the new approach towards these problems proposed in this article and on several occasions before ²⁾.

In presenting this approach to readers of this Review, we are well aware that our reasoning is by no means strictly scientific. When entering the realm of the artist one must not be surprised that in many cases belief will be substituted for knowledge, and, in fact, many things suggested here are difficult to prove in the sense that we can prove a mathematical or physical law.

A scheme of lines, colours and brightnesses

If we want to observe a visual task in comfort, we may analyze our requirements into two groups.

²⁾ L. C. Kalff, Conditions for comfortable seeing, Lecture given at I.C.I. Conference, Stockholm 1951, published also in *International Lighting Review*, Vol. 1951/52, No. 2, 19-26. Comfortable lighting, Lecture given at Meeting of I.E.S. of Great Britain, Eastbourne 1952.

Firstly, we want to see the essential characteristics of the task, the shape, the colour, and the dimensions, and for that reason we sometimes want shadows, highlights or a high level of lighting, or a special colour of light. Secondly, however, we also want to see the task in a concentrated way, i.e. we do not want to be distracted by influences around it.

Now every picture we see, looking at a visual task, consists of three elements: lines, colours and brightnesses, and these three elements are apt to render vision either easy or uncomfortable. Let us consider these three elements separately.

1) Lines

The lines in the picture we see, may be arranged in a rhythmic and quiet way or they may be chaotic. Let us think for instance of looking at a wood of high beech trees, with parallel trunks, and looking at it when we are lying on our back, seeing the criss-cross design of the branches overhead.

The lines in a picture can concentrate our attention on the task, either by pointing towards it or by being arranged concentrically around it. If there are many lines that have not been arranged so and have no relation whatever to the seeing task, they will not be co-operative in concentrating our attention on what we want to observe.

2) Colours

The colours may be divided into two groups: the warm ones, from yellow through orange to red, purple and brown, and the cool ones, from yellowish green to green, blue, violet, grey and black.

The warm colours seem to be the most attractive to us. They also seem to many of us to be nearer than the cold ones. For that reason we should like to concentrate the warm colours on the visual task and its immediate surroundings, whilst we think the cool colours are more adequate for the outer parts or what may be called the background in the visual field.

In practice we unconsciously very often arrange colours in this way. An actress or a singer in a theatre will prefer to appear in a bright and warm-coloured dress against a cool back-ground. One can hardly imagine an artist on the platform in a grey or blue dress against a bright red or orange screen. If we want to decorate the centre of a room by putting flowers on the table, we do not nearly obtain the same vivid impression from blue flowers in a vase on red tablecloth as we do from red, orange or yellow flowers on a green cloth.

3) Brightness

It is generally accepted that the area having the greatest brightness in a picture catches the eye. We can find many examples for this. We put an artist in the limelight, we lay the dining table with a white cloth, the bride is dressed in white. Napoleon chose to sit on a white horse during his battles, etc.

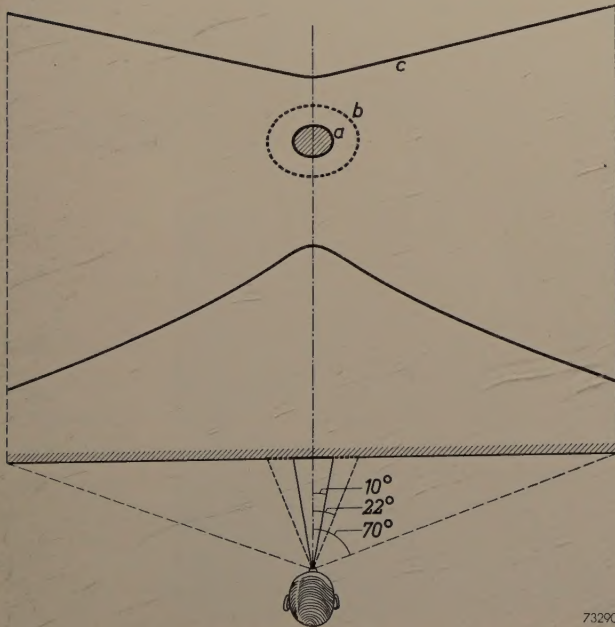
Thus it is only logical that, if we want to keep concentrated on the visual task, this task should be the brightest object in the visual field, its immediate surroundings should be not so bright and the background even less so.

If we now compose a scheme for these three elements in the visual field, we get a picture in which lines, colours and brightnesses co-operate to keep the attention of the observer concentrated on the task.

Of course, when envisaging the practical application of such a scheme, the question arises as to which part of the visual field should be considered as belonging to the "task", which to the "immediate surroundings" and which to the "background". No exact delineation of these parts can be given, but reasonable limits are found by considering the movement of the head and the eyes of a person looking at some object. It is found that an elliptic cone with horizontal apex angle of about $2 \times 10^\circ$ and a vertical apex angle of about $2 \times 8^\circ$ includes all the objects that are examined with moving eyes, without moving the head (fig. 1, a). This is the approximate

angle subtended by an open book of normal size seen from a normal reading distance. This part of the visual field may be regarded as the object of the desirable concentration, i.e. as the task. If an object of rather large size, say, a life-sized portrait, is presented to the average observer, it is found that in order to get a first impression of the picture he involuntarily chooses a viewing distance of about 2.5 times the width or about 3.2 times the height of the picture. Thus, when directing his eyes to one edge of the picture the opposite edge will be situated at an angle of 22° or 17.5° respectively from the viewing direction. The cone determined in this way, of horizontal apex angle $2 \times 22^\circ$ and vertical apex angle $2 \times 17.5^\circ$, may be considered to include the task with its "immediate surroundings" (fig. 1, b). That this cone of vision is not arbitrary but has a real psychological significance is corroborated by the fact that this solid angle approximately corresponds to that part of the retina within which the perception of red and green as colours is possible. Outside of this part of the retina there are only rods, which see differences in brightness but cannot distinguish colours nor perceive small details. This outer part of the field of vision then, represents what in the above was called the "background" and which may be assumed to be of relatively small importance in comfortable seeing (fig. 1, c). We know that vivid brightness contrasts and quick movements can easily be registered from these angles, but that we have to turn our head in order to see what really is the cause of the distraction.

Having settled in a rough way the question of the definition of task, surroundings and background, we are confronted with another, more difficult question: whilst the arrangement of lines and colours is mainly a qualitative matter, the brightnesses of necessity involve a consideration of quantity. Our general scheme only recommends the establishment of suitable brightness differences for concentrating the attention on the centres of interest. Obviously there should be minimum brightness contrasts serving the purpose; a white room with white furniture and a very diffuse lighting is a completely impossible surrounding for comfort. On the other hand, the brightness contrast must not exceed a certain limit, in order to avoid discomfort by glare, etc. Which, then, are desirable and which maximum permissible brightness ratios? A general rule in Brightness Engineering states that the brightness ratio of simultaneously seen objects should not exceed 1:3. Though this rule may be of some help, we are pretty sure that in some cases larger ratios may be applied without impairing comfort: a good impression seems



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Fig. 1. Parts of the field of vision. a area of the visual "task", b immediate surroundings of the task, c background of the visual field. In the latter area colours and small details cannot be perceived. The curiously curved edges of the visual field are due to the cut-off by forehead, nose and cheeks.

largely to depend on the abruptness of brightness variation. In order to get an idea of what is comfortable in this respect, we have constructed spectacles with different sets of glasses, in which light absorbent materials form differently shaped optical wedges, circular and parallel. Experimental work with these spectacles is still in progress.

Practical application of the scheme

The fundamental scheme for lines, colours and brightnesses proposed in the above, of course, will have to be adapted to circumstances. Consider, first, a single person working at a desk. In general, nobody does keep his eyes fixed on the same object for a very long time. Even a person who is writing or reading looks up now and then and likes to fix his eyes on other things, which are a little more distant. These things then become another seeing-task which should present a similar arrangement of lines, colours and brightnesses, in order to be interesting enough. That means a decoration scheme in which there are two centres of interest (*fig. 2*).

For rooms in which people sit, looking in different directions, like dining rooms, board rooms, etc. the scheme has to be altered into horizontal zones of different brightness and colour. For instance in a restaurant the zones of interest in which the seeing-

tasks can be found are the dining table and the faces of the other guests. Over and under these zones the brightness and the warmth of the colours should diminish. For such kinds of rooms it will be advisable, *inter alia*, to keep the ceiling rather dark, either by keeping the light away from it or by giving it a dark colour. Indirect lighting in a restaurant destroys all atmosphere and takes away the attention from the essential things in the room.

Very similar considerations apply to a lounge or lobby: the primary task in this case is found in a horizontal zone, viz. the faces of the other guests; on the other hand, when relaxing or interrupting a conversation, a secondary area of interest should be provided, which obviously should cover again a horizontal zone. An admirable example of a room decorated and lighted in conformity with these views is found in the lobby illustrated in *fig. 3*. The second zone of interest is formed by the grand mural, with a dark panelling underneath and a dark ceiling.

In a church we are inclined to look up. There we may speak of vertical zones, the central one of which has to be brightest and warmest in colour, whilst the zones further away from the centre have to become gradually darker and cooler. *Fig. 4* is a photograph of a church which very distinctly exhibits this scheme of colour and brightness distribution.



Fig. 2. Decoration scheme of a study or office. The person working at the desk cannot keep her eyes fixed on the seeing-task on the desk for a very long time. She will look up now and then to rest her eyes, for which purpose a second centre of interest is provided by a brightly coloured and well lit picture on the wall. The second centre of interest may also be a view through a window, a bunch of flowers or similar things.

Many more examples might be given in order to illustrate our point. In fact, in the decorating practice in Europe of the last five years remarkable instances can be indicated in which the lighting and decorating problems have been tackled with as a background the line-colour-brightness schemes described in this article. Because of our

colour-brightness theories were the principles on which not only the lighting system was based, but which also to a great extent directed the choice of colours and brightnesses of walls, floor and ceiling. It is obvious that in a store the goods to be sold must be the principal items of interest. To this end, local lighting of show-cases and shelves along the



Fig. 3. Lobby of the Automobile Club of Argentina, Buenos Aires. The faces of the guests will constitute a horizontal zone of interest, whilst for relaxation a second horizontal zone of interest is found in the great mural. The concentration on this zone of interest is enhanced by the dark panelling underneath and the dark ceiling.

limited space we can mention only two other cases. Fig. 5 is a photo of a show-window in which the arrangement of lines, all pointing towards one of the centres of interest, greatly contributes to the attention value of this window. Of course, this is not a typical example of the problem of "seeing-comfort" but it is very typical indeed of one side of this problem as analyzed above, viz, the easy "concentration" of the mind of the onlooker. An example encompassing a greater array of structural problems is illustrated in fig. 6. This photograph shows part of a big department store (Vroom and Dreesmann) at Rotterdam. In this project the light-

walls provides the necessary high brightness; this lighting is supported by the concentrated beams of reflector lamps mounted in the ceiling in the louvres which shield the fluorescent lamps giving a general lighting. The rest of the ceiling is completely dark, being painted in night blue and receding into almost complete invisibility behind a grid of light coloured metal strips. This type of ceiling has proved very satisfactory and in recent years has grown rather popular: many decorators in Europe have adopted the "Rotterdam ceiling" when building new or refashioning old department stores. The importance of not distracting the attention by a bright ceiling



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is clearly demonstrated by *fig. 7*, showing a department store decorated on similar lines as the former, but having a ceiling that is painted white and rather brightly illuminated. There can be no doubt that in this case the attention of the visitor is directed to a lesser degree onto the goods in the store.

Gathering of evidence for desirable schemes

It would have been quite natural to end the article at this stage. A theory has been put forth, practical applications of the theory are described and it is shown that satisfactory results are obtained. However, it must be admitted that the theory is not founded on facts but rather on intuition. Such a peculiarity should not prevent the artist from bringing the theory to life in his creations. It never did. But on the other hand, lighting experts generally are of a more scientific mind and will feel a dire need of some evidence of the soundness of the proposed scheme.

Fig. 4. Interior of church at Venray (Netherlands), showing vertical zones, with highest brightness and warmest colours (white, red and gold) in the central zone; in the outer zones dark stone columns with shadows prevail.



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Fig. 5. Show-window, containing several centres of interest. By the lines pointing to the chief centre and by a distribution of colours and brightness according to the scheme exposed in this article a high attention value of this window is obtained.

For their purpose the evidence found in the results of applications of the theory will not suffice, as these results quite naturally also depend on many other factors. More direct evidence, obtained in experiments eliminating most of the incidental and complicated influences occurring in practice, may be

persons to whom seeing and constantly analyzing what they see has been the most important part of their activities, and who have more or less consciously played on human reactions to visual impressions: the painters. Now, it is indeed a very interesting experience to go through a museum



Fig. 6. Part of the department store of Vroom and Dreesmann at Rotterdam. The merchandise is made the centre of interest throughout by local lighting of a high level. The ceiling is painted dark blue. In each quadrangle of the ceiling either a lighting unit, a loudspeaker or a clock can be mounted. The general lighting is effected by means of groups of two 40 W fluorescent lamps with two 68 W incandescent reflector lamps employed as ballasts, each group being inserted in two adjacent quadrangles of the ceiling (in this part of the store double groups are used). As the ceiling itself, lying above the bright metal strips, is almost completely invisible, the architects obtained here an easy method of concealing and at the same time keeping accessible the wiring and plumbing of the store, as well as the ducts for air conditioning. This "Rotterdam ceiling" has since been adopted by a score of department stores in Europe.

desirable. In the following a few efforts to produce such evidence will be described. Strange though it may seem to bring forth evidence for a theory only after its extensive application, we feel justified in this procedure, as we do not wish to blur the role of intuition in our approach to the lighting problem.

Since time immemorial there has been a group of

of pictures and to analyze in how far the different works of art are in accord with the principles exposed in this article. We have found that most of the pictures which have been composed as free works of art, inviting quiet contemplation and which have got no other aim (as e.g. giving a mental shock), exhibit more or less clearly our fundamental

schemes of colour, line and brightness. An example is shown in *fig. 8*³⁾.

This is still a kind of indirect evidence. Experiments with the aim of obtaining direct evidence for our views were set up in the "Demonstration



Fig. 7. Department store of Vroom and Dreesmann at Haarlem. The decorating and lighting system is similar to that of Rotterdam (*fig. 6*), but the ceiling is given a brightly painted surface with a high lighting level. The concentration of attention on the merchandise in this case is in our opinion markedly less.

Laboratory" at Eindhoven, inaugurated in May 1951. A few of the facilities of this Laboratory are shown in the following illustrations.

Fig. 9 is a booth in which the different decoration schemes are made visible in a niche. They can be illuminated with different intensities and are in the shape of little metal doors, so that the different schemes can be observed one after the other by simply turning over the panels like the pages of a book. In succession schemes are shown that are and others that in one way or another are not in keeping with our theories, and the preference of the observer is noted.

Fig. 10 shows an entire room in which the colour and lighting scheme can be changed. The walls

consist of turning panels, so that they can be made white, a dull green or in elmwood. The tops of the tables can revolve, and so take the colours of the elmwood or the green walls. Several paintings are hung in this room: the front sides in a colour and line composition obeying the rules of our scheme, the backs in an opposite arrangement. By changing the lighting systems and the colours and reflections of walls and paintings, different aspects and atmospheres can be offered to the spectators in this room, so that a preference for certain combinations of colours and brightnesses can be traced.

We cannot dwell on other possibilities of experimentation provided in the Demonstration Laboratory. Suffice it to say that many hundreds of persons have gone through the experiments, contributing by their reactions to our knowledge of the subject. On the whole these reactions give us reason to believe that we are working in the right direction.

It must be well understood that what we have done here is not an attempt to give recipes for artistic effects. We think that our lines-colours-brightness schemes may be useful because they respond to the way man is thinking and subconsciously reacting to the lines, colours and brightnesses he takes in through the eyes. The schemes are simple and understandable for both lighting expert and artist, but they are so vague as to leave enough freedom to the creative mind. Their chief importance may well be that they will convince the artist of the fact that "light is part of the picture" and so should be part of his activity, whilst on the other hand they will show the lighting man that a lighting system or a lighting level are not things to be planned apart and without intense co-operation with the artist.

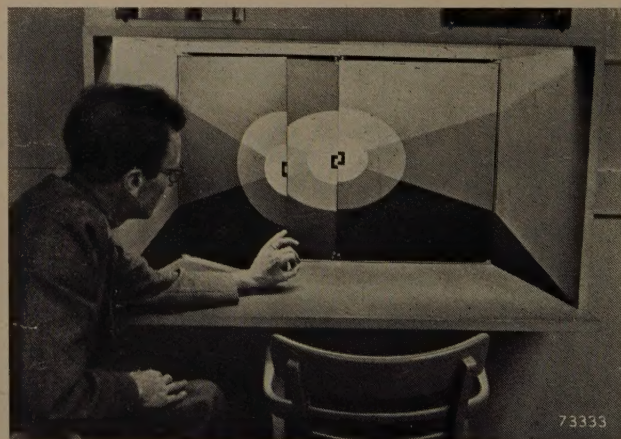


Fig. 9. Niche in the Philips Demonstration Laboratory at Eindhoven, where a number of different lines-colours-brightness schemes can be presented to a spectator.

³⁾ Other examples are to be found in the article in *International Lighting Review* quoted in footnote ²⁾.



Fig. 8. The doge Leonardo Loredan, by Giovanni Bellini (about 1430-1516). This famous portrait exhibits very clearly a scheme of lines, colours and brightnesses, concentrating the attention on the warm-coloured face with the strong contrasts of the dark eyes. Lines of the collar and the hat with its ribbons are arranged concentrically around it, the lines of the shoulders and the row of buttons point towards it and the blue-green (originally pure blue) background is cool and receding, whilst its brightness rapidly diminishes near the frame.

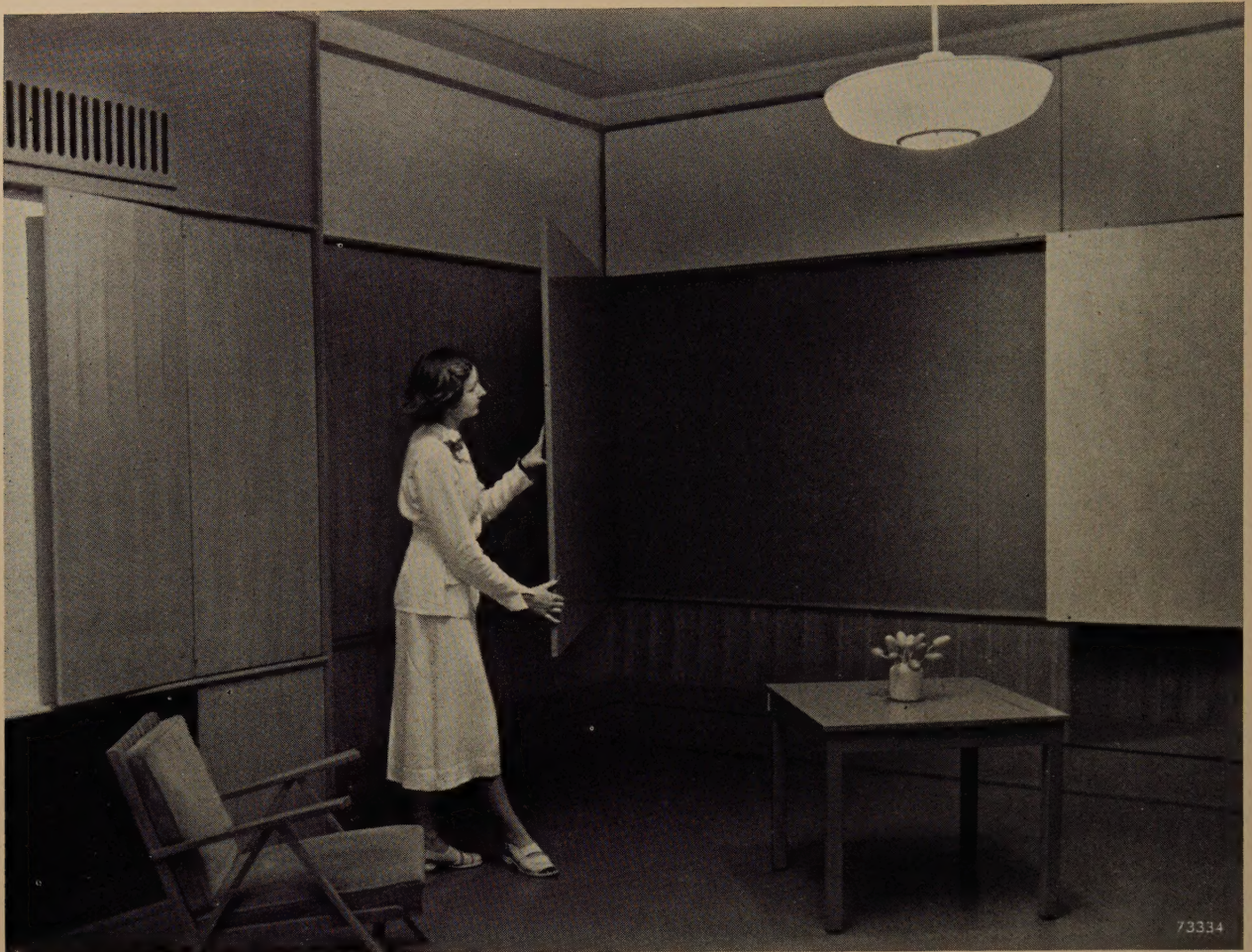


Fig. 10. Test room in the Demonstration Laboratory. Not only the lighting system but also the colours of the walls and the furniture and pictures can be easily changed.

Experience gained so far in our Demonstration Laboratory, where our theories are brought to the public and where considerable interest in them has been shown by artists, architects and interior decorators as well as by lighting experts, has been highly encouraging and has reinforced our confidence that fertile cooperation between these groups is possible.

Summary For a number of years, efforts have been made to avoid discomfort in modern lighting installations by means of

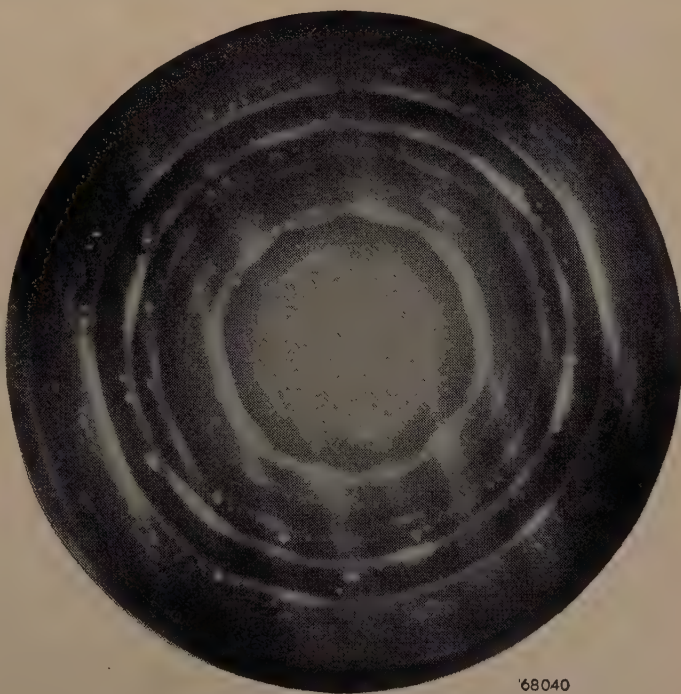
“Brightness Engineering”. The author holds that instead of trying to avoid discomfort we should aim at creating comfort. This aim can only be achieved by co-operation of the lighting expert with the architect and decorator. As a starting point for such a co-operation the author proposes a scheme of lines, colours and brightnesses suitable for concentrating the attention on a visual task. The adaptation of this scheme to different situations is discussed, viz. for a single person working at a desk (for which case two centres of interest should be present), for a restaurant or a lobby (horizontal zones), for a church (vertical zones), and for a department store (a number of centres of interest). Illustrations of the practical realization of the scheme in such cases are given. Evidence for the soundness of the basic lines-colours-brightness scheme is obtained from an analysis of famous paintings and from experiments made in the Demonstration Laboratory at Eindhoven.

ASBESTOS, VIEWED THROUGH THE ELECTRON MICROSCOPE



The fibrous structure of asbestos is due to the fact that the crystals comprising the material (a magnesium silicate of variable composition) have, for the greater part, a long-drawn-out shape, frequently in the form of fine tubes. The magnification of the photograph is $30\,000\times$.

The adjacent electron diffraction diagram, taken for the square indicated in the photograph, shows clearly the consequence of the preferred orientation of the group of crystals, which lie practically parallel in their longitudinal axes. The diffraction diagram was taken with the electron microscope by the method described at the time in this Review (Philips Technical Review 12, 33, February 1950).



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AN ELECTRICAL ROUGHNESS TESTER FOR THE WORKSHOP

by G. W. van SANTEN.

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It is natural to try to test the roughness of a surface by scratching it with the nails. The same method is applied when testing the hardness of a relatively soft surface, e.g. a layer of paint. Naturally, this test is merely subjective; since this is a drawback, various attempts to find a more objective testing method were made. In the preceding volume of this review an instrument used for testing paint was discussed, which makes an impression in the layer of paint in a reproducible manner and measures its depth electrically. In the present article the author describes an instrument giving an indication of roughness measured electrically. This instrument was designed for the workshop in the first place and not especially for the laboratory, as are the expensive roughness meters already in existence.

The proper performance and the life of machine parts rubbing against each other, e.g. spindles in bearings, and pistons in cylinders, not only depend on the material, the clearance and the lubrication, but also and to a high degree on the smoothness of the surfaces moving against each other. The designer of a machine will accordingly not only specify its materials and clearances but also its roughness, or in other words, the smoothness to which the surfaces should be finished.

We can only inspect to see whether or not the latter requirement has been met if we have an instrument at our disposal that is suitable for assessing the roughness of a surface, or at any rate for comparing it with that of a sample surface. Several instruments like this are commercially available¹⁾. Most of them are very expensive instruments, however, designed for the laboratory and less suitable for the workshop. In most cases they are more accurate than necessary for the workshop and too unwieldy to handle. For this reason there is a great need for a roughness tester of a more simple and robust design, easy to handle and therefore suitable for the workshop. The electrical roughness tester discussed in the present article seems to fill this need.

A better international specification of roughness standards is no less urgently required. In the Netherlands the Central Standardization Committee has set up a Sub-Committee for Surface Conditions; this committee has concerned itself in great detail with this problem of roughness standardization. After numerous discussions with representatives of engineering works at home and abroad it has drawn up a draft standard (sheet N 785); we shall mention the main points of this presently.

This draft standard has already been adopted in the Dutch Philips factories, which are dispersed across the country. Because of this dispersal a number of standard samples and derived sub-standards, in which certain numerical roughness values had been laid down, were needed to effect the adoption; the manufacturing products were compared with these sub-standards after their distribution amongst the various factories. A subjective comparison by eye or touch of nail is unreliable and of no use at all in the event of arbitration. The tester to be discussed, however, is suitable for an objective comparison.

The standard samples mentioned above were manufactured in the Philips factories at Eindhoven, by turning, grinding or otherwise machining metal surfaces until the required smoothness was obtained; this was assessed by means of various laboratory instruments. The sub-samples were derived by electro-deposition from these sample surfaces.

The Dutch Standardization Draft

The design of the Philips roughness tester is closely connected with the Dutch Standardization Draft. We shall first, therefore, discuss the chief items of this draft:

- 1) definition of the concept of roughness,
- 2) determination of a unit for the evaluation of roughness,
- 3) the laying down of roughness classes and dimension groups, i.e. subdivisions of the classes.

We shall discuss these items successively.

Definition of roughness

Fig. 1a represents the profile of a machined surface, much enlarged; the cross-section is perpendicular to the direction of machining, e.g. the grooves left by a cutting-tool on turning or planing.

¹⁾ H. Becker gives a survey: Methods of measurement and definition of surface, *Microtecnic* 4, 180-184, 276-282 and 302-307, 1950.

- The roughness of a surface such as this can be defined by four methods:
- a) the maximum difference in height between peak and valley,
 - b) the difference in height between the highest peak and the mean level,
 - c) the root mean square value ($h_{r.m.s.}$) of the deviation h from the mean level:

$$h_{r.m.s.} = \sqrt{\frac{1}{l} \int_0^l h^2 dx},$$

- d) the mean value h of the absolute value of h :

$$h = \frac{1}{l} \int_0^l |h| dx. \quad (1)$$

The mean level mentioned in (b),(c) and (d) is the level resulting from a hypothetical rolling of the peaks into the valleys, giving an absolutely smooth surface. In the definitions (c) and (d) x stands for the co-ordinate along the reference line (the line of intersection of the mean level and the plane of the drawing) and l for a length great in comparison with the average distance from groove to groove. The Dutch draft is based on the mean value.

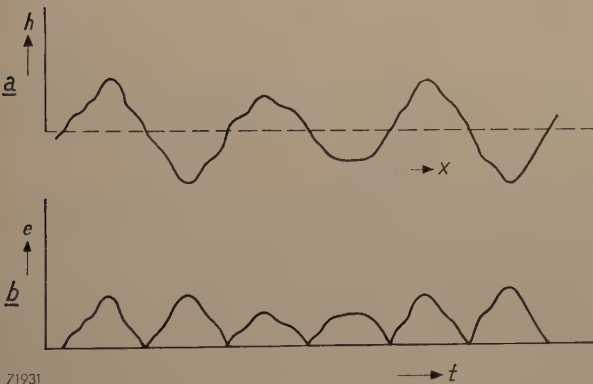


Fig. 1. a) Cross-section of a machined surface, perpendicular to the machining grooves (much further enlarged in the direction h than in the direction x).
b) Voltage e arising after full-wave rectification of the alternating voltage, excited by an electric pick-up on exploring the surface (a), as a function of the time t .

It is a short-coming of the definition (a), on which the German standard sheet DIN 4762 is based, and of the definition (b), which is advocated in France, that quite different results may be obtained from measurements made in different spots, since we may happen upon a particularly high peak or deep valley; with the definitions (c) and (d), on the other hand, a minimum measuring length l may be specified of such a size as to make the measuring result independent of l .

The American standard ASA B46 is based on the root mean square value, the British standard BS 1134 on the mean value. The Dutch committee has thought fit to conform to the latter, since measurement of the mean value is simpler and the concept can be better explained in the workshop. In practice it has been found that the difference between r.m.s. and mean values is negligible.

Roughness unit

A second important point in the Dutch draft is the introduction of a unit of roughness: the ru, a name to be taken as an abbreviation of the English “roughness unit”, the French “rugosité” or the Dutch „ruwheid”. The roughness of a surface amounts to 1 ru if

$$h = 1 \text{ micro-inch} = 25.4 \times 10^{-6} \text{ mm.}$$

Roughness classes and dimensions of surfaces

A system of symbols for the indication of the required roughness on technical drawings has already been adopted for a long time, e.g. $\nabla\nabla$ for what might be called “plain finished”, $\nabla\nabla\nabla$ for “smooth finished”, etc. These definitions are naturally vague and subjective. The most simple solution would be to replace them by a quantitative specification with a certain number of roughness units, say $\nabla\nabla = 125 \text{ ru}$, $\nabla\nabla\nabla = 32 \text{ ru}$, etc. However, an absolute classification like this would cause difficulties since different groups of technical people attach widely divergent meanings to such definitions as “plain finished”, “smooth finished”, etc.: a railway engine designer may call a surface smooth which is very rough to a designer of precision instruments. In analogy to the well-known ISA-system of limits and fits, the Dutch draft standard N 785 meets this difficulty by a relative classification, viz. by relating the number of ru, ascribed to the symbols, to the dimensions of the surface under discussion. This dimension ϕ stands in the case of a spindle for the diameter, in the case of a rectangular surface for the side perpendicular to the machining grooves, etc. The symbol $\nabla\nabla\nabla$ indicates a roughness of 32 ru if ϕ lies between 18 and 50 mm, but a roughness of 25 ru if ϕ lies between 6 and 18 mm, and of 40 ru for ϕ between 50 and 120 mm. Every roughness class is consequently subdivided into groups, as shown in the following table, giving a division into seven roughness classes, R_0 - R_6 ; each class is indicated by two roughness symbols, used according to the machining (see notes *) and **).

Table. Classification as to roughness, depending on the dimension σ of the surface, according to the Dutch standardization draft N 785.

Roughness class	R ₀	R ₁	R ₂	R ₃	R ₄	R ₅	R ₆
Roughness symbols *)	~	○	○○	○○○	○○○	●○○	●●●
Roughness symbols **)	▽	▽	▽▽	▽▽▽	▽▽▽	▽▽▽	▽▽▽
Dimension σ mm	Roughness μ						
< 6	1250	315	80	20	5	1.2	0.3
6- 18	1600	400	100	25	6	1.6	0.4
18- 50	2000	500	125	32	8	2	0.5
50-120	2500	630	160	40	10	2.5	0.6
120-250	3150	800	200	50	12	3	0.8
> 250	4000	1000	250	63	16	4	1

*) Roughness symbols for surfaces with machining allowance and shaped by chip removal. (A machining allowance is an extra quantity of material on the work-piece, at those spots where machining has to be carried out.)

**) Roughness symbols for surfaces without machining allowance and shaped by chip removal, or for surfaces not shaped by chip removal.

The symbols *) hold good for e.g. a spindle that has to be turned down to a certain diameter, the symbols **) e.g. for a moulded workpiece that has to be polished. For simplicity's sake we shall only discuss the symbols *) in this paper.

Principle of the roughness tester

The roughness tester under discussion consists of a pick-up, an amplifier, a rectifier and a moving coil instrument (fig. 2). The roughness pick-up has

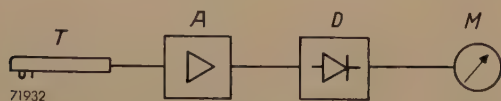


Fig. 2. Block diagram of the Philips roughness tester. *T* pick-up, *A* amplifier, *D* rectifier, *M* moving coil meter.

some analogy to a gramophone pick-up with one important difference in design, however: the former has to respond to irregularities in a direction perpendicular to the explored surface, the gramophone pick-up on the other hand to the undulations of the groove in the surface of the record.

The pick-up is moved by hand across the surface to be examined, approximately perpendicular to the direction of machining. At constant speed — we shall explain presently that this is by no means a necessary condition — it yields a voltage which is the same function of time as h is of x . This voltage is amplified by the amplifier. Rectification of the output voltage yields a direct current that is proportional to h (fig. 1b), i.e. to the roughness to be assessed. This direct current is measured with the moving coil meter.

Construction

The roughness tester is shown in fig. 3. A few particulars are discussed below.

The pick-ups

The cross-section of a pick-up which is used for most purposes is shown diagrammatically in fig. 4. It is of the piezo-electric type, since the smallest dimensions can be obtained in that way, which is

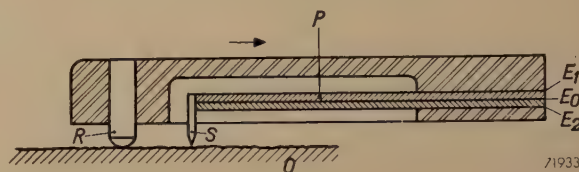


Fig. 4. Schematic longitudinal section of the pick-up, *P* piezo-electric element, consisting of two plates of barium titanate, and the electrodes *E*₁, *E*₂ and *E*₀. *S* stylus (pointed sapphire). *R* reference pin gliding across the tops of the irregularities of the surface *O*.

important for two reasons. In the first place, if the dimensions of the pick-up are small, the resonant frequencies of the moving parts lie above the vibration frequencies of the stylus when used normally, and consequently the resonances have no disturbing influence. In the second place, it is important for the dimensions of the pick-up to be small if the inner wall of small drilled holes has to be examined.

The pick-up rests with the pin *R* on the surface to be explored. The radius of curvature of this pin is large in proportion to the distance between the grooves, consequently the lower end of the pin remains at an approximately constant level, whilst the pick-up is moved across the surface, the reference level, in this case the plane through the peaks of the irregularities. A second pin, the stylus (*S*), consists of a sapphire with a radius of curvature of 60 μ . This is small enough for the stylus to follow the irregularities closely, even if the groove distance is 16 μ , and yet not so small that the point is easily injured or the surface scratched. The stylus is attached to one end of a piezo-electric element, the other end of this element being clamped to the body of the pick-up. As the pick-up travels along a surface, the movement of the element varies in accordance with the irregularities in the surface. Consequently, an alternating voltage is excited between the electrodes *E*₁ and *E*₂ attached to the upper and lower sides of the element. This voltage as a function of time is a copy of the irregularities. Fig. 5 is a photograph of this pick-up.

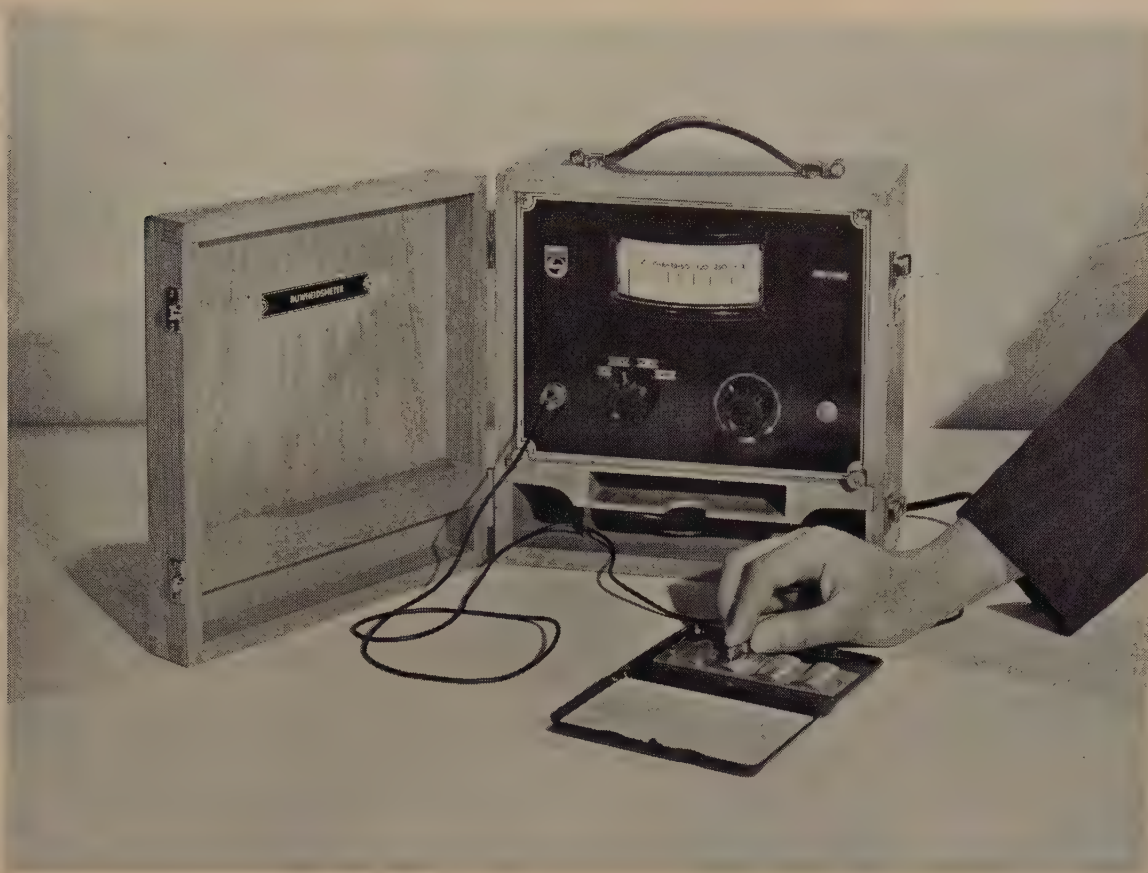


Fig. 3. The Philips roughness tester type PR 9150. Below the dial: to the left a knob for adjustment to one of the four roughness classes, to the right a correction knob. The pick-up is here traversing a sample plate of verified roughness (roughness standard); the pointer should reach to a certain calibration mark on the dial. Below the front plate is a space for the pick-ups, the flexes and the box containing the four different roughness standards (type PR 9180).

The piezo-electric element consists of two plates of barium titanate (BaTiO_3)²⁾, with the outer

electrodes E_1 and E_2 and a central electrode E_0 (fig. 4). The barium titanate receives its piezo-electric properties from a polarization effected during the manufacturing process by connecting a direct voltage source between the electrode E_0 and the

²⁾ J. H. van Santen and G. H. Jonker, Electrical, more especially piezo-electric, properties of barium titanate, T. Ned. Radiog. 16, 259-274, 1951 (No. 6) (in Dutch).

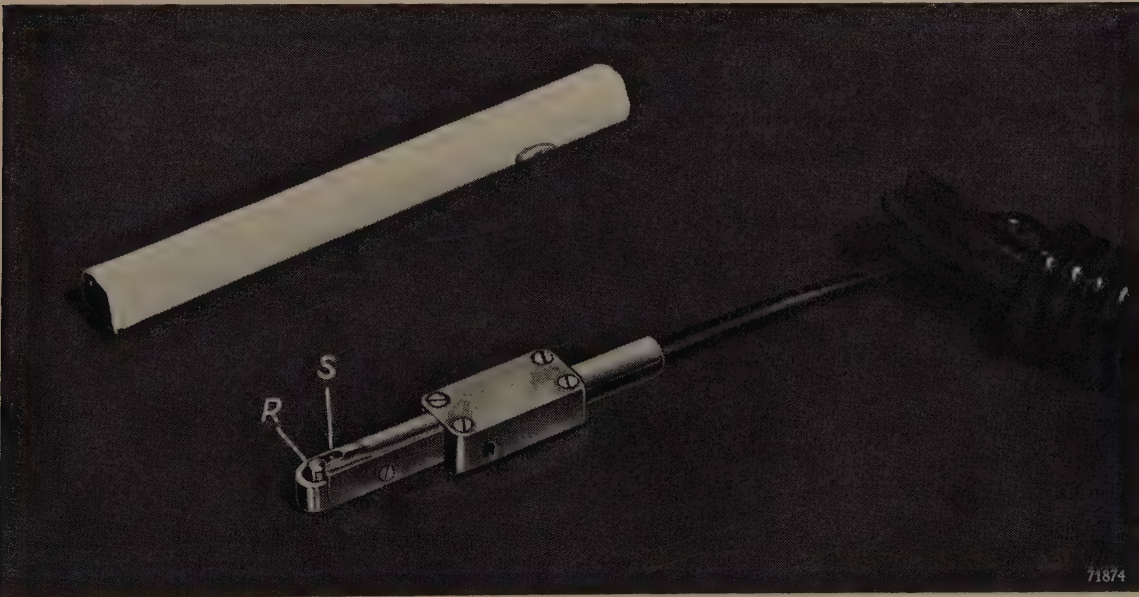


Fig. 5. The pick-up with the stylus S and the reference pin R , pointing upwards.

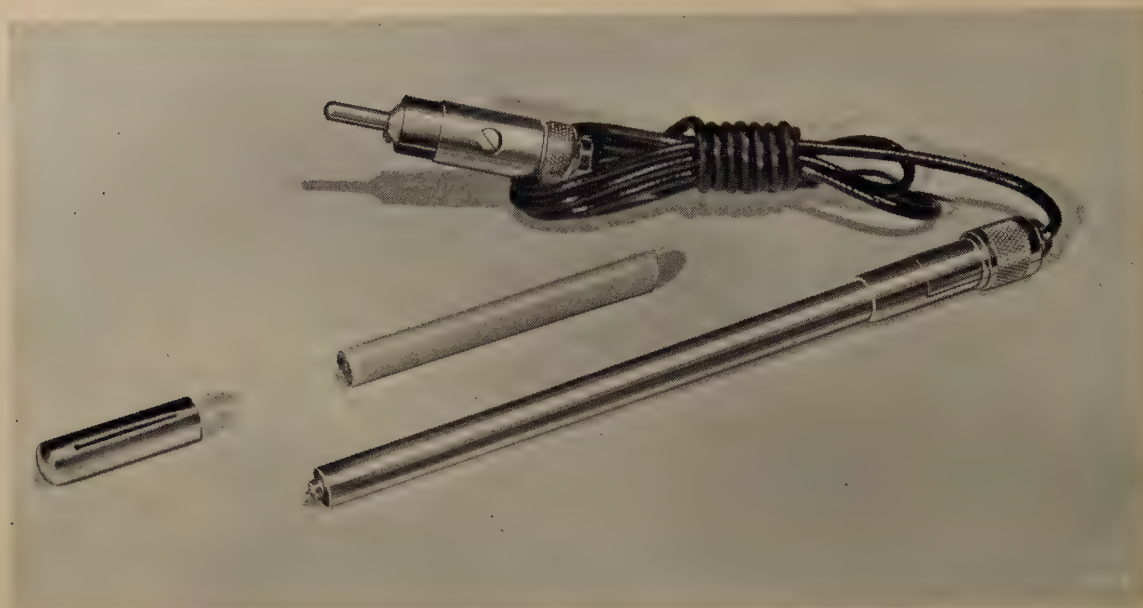


Fig. 6. Special pick-up for the examination of spots inaccessible to the pick-up shown in fig. 5.

temporarily short-circuited electrodes E_1 and E_2 ³⁾. Afterwards E_1 and E_2 are disconnected and E_0 is no longer used. Barium titanate is to be preferred to piezo-electric materials such as Rochelle-salt, because it is heat- and damp-resistant, and also to quartz because it is more sensitive and less expensive.

The height and width of this pick-up are so small (7 mm $\times$ 4 mm) that it is still suitable for investigating the inner surface of an 8 mm hole.

The shape of the pick-up under discussion makes it unsuitable for some purposes, e.g. exploring the bottom of a so-called blind-hole (hole with flat bottom). For this reason a second pick-up was designed, rod-shaped (fig. 6), about the size of a pencil. The stylus is again a pointed sapphire, but otherwise the design differs considerably from the first pick-up. Longitudinal section (fig. 7) shows that the vertical movements of the stylus are transmitted by pieces of rubber, which exert a varying pressure on the piezo-electric element. In this case the element consists of a tube of barium titanate, with an inner and an outer coating of metal. The varying pressure excites an alternating voltage between the coatings.

The resonant frequency of this pick-up is determined by the total mass and the rigidity of the rubber. This resonant frequency should be much lower than the vibration frequencies of the stylus. The mass of the pick-up hardly follows the movement of the stylus, in this case, and the voltage

obtained is a faithful copy of the stylus movement, i.e. of the irregularities.

Since this pick-up has no reference pin, the force exerted on it by hand is completely transmitted to the workpiece by the pointed stylus. This necessitates cautious handling to avoid scratches. This danger is much smaller when the first mentioned

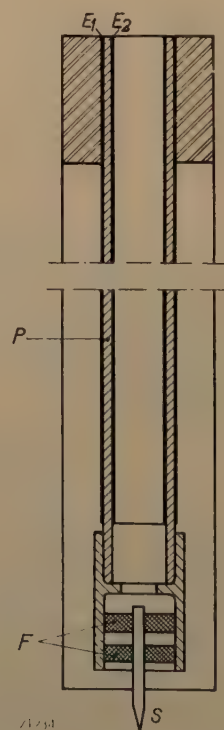


Fig. 7. Longitudinal section of the special pick-up shown in fig. 6. S stylus (pointed sapphire). F pieces of rubber. P piezo-electric element (tube of barium titanate, with electrodes E_1 and E_2).

³⁾ The fact that a permanent polarization can be induced in barium titanate, was already mentioned in Philips techn. Rev. 11, 150, 1949.

pick-up is used; whenever the shape of the workpiece is suitable this pick-up is, therefore, used for preference.

Characteristics of pick-up and amplifier

Two factors should influence the measuring results as little as possible: the speed with which the pick-up is moved and involuntary movements of the hand.

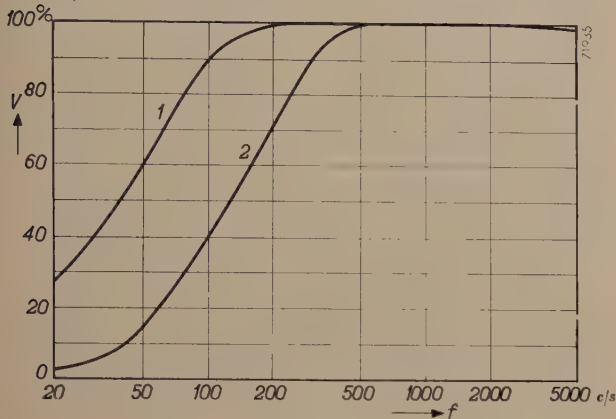


Fig. 8. Overall characteristics of pick-up and amplifier: output voltage V of the amplifier as a function of the frequency f , at constant amplitude of the sinusoidal stylus displacement. Curve 1 is used for "plain" ($\nabla\nabla$) and "smooth" ($\nabla\nabla\nabla$) machined surfaces, curve 2 for "very smooth" ($\nabla\nabla\nabla\nabla$) and "specially smooth" ($\nabla\nabla\nabla\nabla\nabla$) machined surfaces. (For the meaning of the roughness symbols, see table.)

The speed with which the pick-up is easily moved lies between about 5 and 10 cm/s. Let us suppose the maximum distance between irregularities to be 0.4 mm, which is found in case of "plain finished" surfaces; fundamental frequencies of 125 to 250 c/s will in that case arise during a normal exploring process. The involuntary movements of the hand have much lower frequencies. The frequency characteristic, i.e. the output voltage of the amplifier as a function of the frequency f , at a constant amplitude of the sinusoidally moved stylus, is shaped like curve 1 in fig. 8. It is flat for frequencies from 150 to 5000 c/s and drops steeply below 100 c/s. This shows that the undesirable voltages with very low frequencies are attenuated and that the required ones are amplified, independently of the speed with which the pick-up is moved, provided that this speed is not too low.

The speeds of a few cm/s mentioned above compare favourably with the much lower speeds of some other roughness testers. In these instruments the movement of the stylus is transmitted by means of relatively heavy parts to an element yielding a voltage. The frequency of the stylus has to be low in comparison to the already low resonant frequencies of this mechanical transmission system. For this reason the speed

of the tester has to be very low (a few mm a minute). The tester can hardly be moved by hand so slowly, and it has therefore to be driven mechanically. The measuring takes a long time, which is another disadvantage.

If the surfaces are smoother, involving smaller irregularities, the involuntary movements are relatively stronger. For this reason we change over to characteristic 2 (fig. 8), which already begins to drop at 500 c/s. This is permissible since the irregularities lie closer together if the surfaces are smoother and the vibration frequencies are consequently higher (fundamental frequencies of 1000 to 2000 c/s).

The characteristics of fig. 8 are achieved by means of filters in the amplifier.

Use of the roughness tester

The object in view when using the roughness tester is the determination of the roughness class of a surface in accordance with the specification. We have limited ourselves to the classes R_2 , R_3 , R_4 and R_5 , which occur in the vast majority of cases.

An attenuator with four positions, marked $\nabla\nabla$, $\nabla\nabla\nabla$, $\nabla\nabla\nabla\nabla$ and $\nabla\nabla\nabla\nabla\nabla$ (fig. 3), is found at the input end of the amplifier. We will assume that a surface that should have the roughness class R_4 ($\nabla\nabla\nabla\nabla$) has to be examined; we shall suppose first that the surface size falls in the group $\sigma = 18$ to 50 mm. We then proceed as follows.

The attenuator is set in the position corresponding to the roughness class expected, thus in this case to the position $\nabla\nabla\nabla\nabla$. Four calibrated roughness standards are supplied with the instrument (see below). The standard bearing the same symbol, $\nabla\nabla\nabla\nabla$, is selected; its roughness is 8 ru (the dimensions of the standards are 38 mm $\times$ 50 mm; they fall, therefore, in the group $\sigma = 18$ to 50 mm). The degree of amplification is adjusted by means of a fine adjustment knob (fig. 3) in such a way that the meter deflects to the calibration mark belonging to $\sigma = 18$ to 50 mm, approximately in the centre of the dial (fig. 9). Thereupon the pick-up

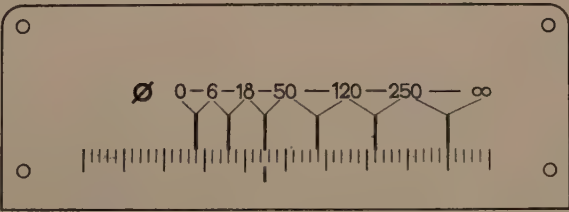


Fig. 9. Dial of the roughness tester. The thick vertical marks are reference marks, the first for surfaces with the dimension σ between 0 mm and 6 mm, the second for surfaces with σ between 6 mm and 18 mm, etc.

is moved across the surface to be examined. If the pointer of the meter is deflected more than previously, this surface is still too rough; if it is deflected less, it is already smoother than demanded.

If the dimension of the object had fallen into another group, e.g. $\phi = 120$ to 250 mm, a roughness of 12 ru (instead of 8 ru) would, according to the table, have been indicated by $\nabla\nabla\nabla$, and the mark between the numbers 120 and 250 would have served as calibration point. Other calibration marks have been added for other groups of dimensions: $\phi < 6$ mm, $\phi = 6$ -18 mm, etc. (fig. 9).

Roughness standards

A box with four roughness standards (fig. 3) is supplied with the meter, each standard $38 \text{ mm} \times 50 \text{ mm}$ in size:

$\nabla\nabla$ turned	... 125 ru
$\nabla\nabla\nabla$ turned	... 32 ru
$\nabla\nabla\nabla$ turned	... 8 ru and
$\nabla\nabla\nabla$ superfinished	... 2 ru

Being chrome-plated, the standards retain their roughness calibration for years.

The inaccuracy of these roughness standards is less than $\pm 10\%$, whilst that of the measurement itself is less than $\pm 20\%$. So the error in the overall result does not exceed $\pm 30\%$. This is amply sufficient for our object, since the successive roughness classes differ from each other by a factor 4 (see table).

Summary. The roughness tester discussed above consists of two pick-ups, one amplifier, a rectifier and a moving coil meter. One of the pick-ups, which are somewhat analogous to a gramophone pick-up, is moved by hand across the surface to be examined (speed: a few cm/s). The pick-ups contain a pointed sapphire as stylus. This stylus affects a piezo-electric element of barium titanate, a material which is heat- and damp-resistant. The two pick-ups differ in form in such a way that nearly all places are accessible to one or the other. The alternating voltage obtained is amplified and rectified and the mean value of the rectified voltage is measured by means of a moving coil meter. The deflection, therefore, indicates the mean value of the irregularities, in conformity with the standardization adopted in the Dutch Philips Works. According to this standardization the roughness of a surface is 1 ru if the mean irregularity amounts to 1 micro-inch. Moreover, the connection existing between the roughness expressed in ru, the "roughness class" (indicated by symbols such as $\nabla\nabla$, $\nabla\nabla\nabla$, etc.) and one of the dimensions of the object was laid down. The dial of the roughness tester was graduated accordingly. Four roughness standards are accessories to the meter (125, 32, 8 and 2 ru).

A 3 cm-MAGNETRON FOR BEACONS

by G. A. ESPERSEN *) and B. ARFIN *).

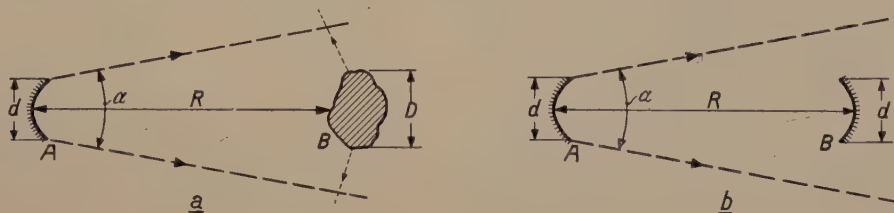
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The universal acceptance of the magnetron as a pulsed oscillator for decimetric and centimetric waves is mainly due to the very high peak powers it can deliver — an essential requirement in radar, linear accelerators etc. There is, however, a need also for pulsed oscillators of comparatively low peak powers, viz, in beacon systems. This article shows how a magnetron for such a purpose has been designed under severe restrictions of weight and heater rating and how typical requirements of tuning facilities and frequency stability have been met.

Introduction

This paper will deal with a magnetron developed for beacon systems. Such a magnetron must meet rather severe requirements of frequency stability. In fact, the most important task of a beacon is to convey to distant receivers the information of its presence; for the receiving aircraft or ship it may be a matter of life or death if the absence of a signal is mistaken for an absence of the beacon. So the

available to be picked up by a receiver in the case of a beacon, or to be reflected by an obstacle in the case of radar. In the radar case, however, the signal must travel a distance R back to the transmitter again so that only a small fraction of the reflected energy will arrive at the radar receiver. The signal to be detected in this case is $8R^2/D^2$ times smaller than with the beacon, D^2 being the effective area of



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Fig. 1. a) Schematic drawing of a radar system. The object B of area D^2 at distance R receives a fraction $(D/\alpha R)^2$ of the electromagnetic energy emitted by the transmitting antenna A into the solid angle α . If this energy is scattered back uniformly into half the space, a fraction $d^2/8R^2$ thereof is caught by the antenna A being at the same time the receiving antenna (diameter d). So an energy of only about $\frac{D^2}{\alpha^2 R^2} \times \frac{d^2}{8R^2}$ times the transmitted energy must be detected in the receiver.

b) Schematic drawing of a beacon system. If the receiving antenna B is of the same size (diameter d) as the transmitting antenna A , an energy of $d^2/\alpha^2 R^2$ times the transmitted energy is received. The signal, then, is $8R^2/D^2$ times larger than in the case of radar,

magnetron frequency must stay within the band of the receivers despite all possible changes in operating conditions (ambient temperature, output circuit impedance). Moreover, a beacon magnetron must be tunable in order to be able to avoid the frequency bands of other beacons and to compensate for the frequency spread of normal fabrication.

On the other hand, the power of a beacon magnetron can be much less than that of the better known conventional radar magnetrons. This will be clear from a glance at fig. 1a and b. At a distance R only a minute fraction of the transmitted energy is

the obstacle (the receiving antenna in both cases being supposed to be of equal size as the transmitting one). For $R = 10$ km, $D = 10$ m, this factor amounts to nearly 10^7 . Hence, whereas radar magnetrons produce powers in the order of hundreds of kilowatts, beacon magnetrons, though usually used with a smaller antenna, must supply only several dozens of watts.

At Philips Laboratories, Irvington (U.S.A.), a beacon magnetron was developed which satisfied the following conditions ¹⁾:

*) Philips Laboratories, Inc., Irvington-on-Hudson, N.Y., U.S.A.

¹⁾ G. A. Espersen and B. Arfin, Low-voltage tunable X-band magnetron development, Tele-Tech, June 1951, p. 50-51 and 84, and July 1951, p. 30-31.

Frequency: nominal 9310 Mc/s, variable from 9300 to 9320 Mc/s (wavelength 3.2 cm).
 Peak power output: minimum 50 W, normal 100 W.
 Duty cycle: maximum 0.003.
 Pulling figure ²⁾: 6 Mc/s.
 Frequency variation under temperature variation of $\pm 40^\circ\text{C}$: not more than ± 3 Mc/s.
 Frequency variation when duty cycle is changed: not more than ± 1 Mc/s.

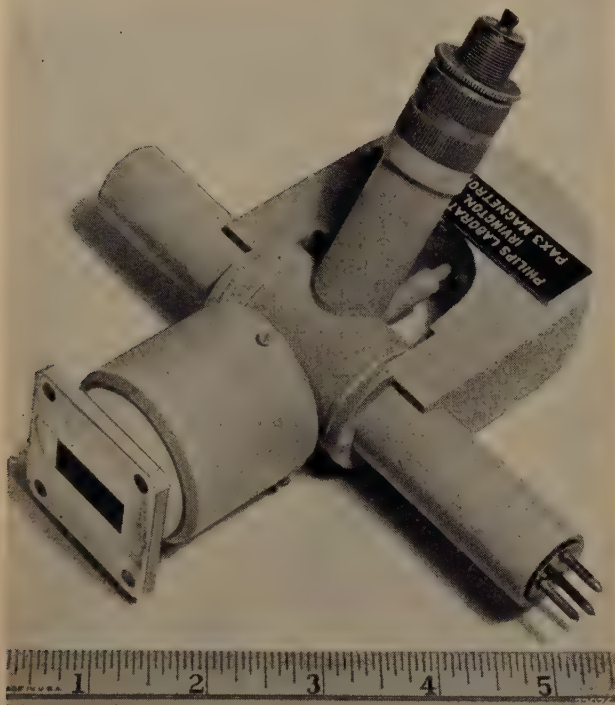


Fig. 2. Photograph of complete magnetron, type PAX3 (3 cm wavelength, 100 watts peak power), with attached magnet.

In view of the low power required, it should be possible to operate the tube with a rather low anode voltage and low cathode heater rating. Moreover, it should be possible to cut down the weight considerably, which may be of importance for portable, semi-permanent type beacons. Desirable ratings are: anode voltage 800 V, heater rating of 6.3 V, 300 mA, and total weight less than 1150 g. The efficiency should be about 30%.

Fig. 2 is a photograph of the complete magnetron (type PAX3) with its magnet; fig. 3 shows some important parts of it. The design of this magnetron will now be discussed.

Type of resonators

The rising sun type of anode (see I) was chosen, comprising a number of alternately large and small resonance cavities. This anode has several advantages as compared with the strapped anode version: the internal losses are smaller; fabrication is easier, resulting in greater uniformity from tube to tube; greater mode separation is possible (as explained in I, a certain separation of the wavelengths of different modes of oscillation is necessary); finally, designs having not very different characteristics were already known in the rising sun type.

Shape and dimensions of the interaction space

The interaction space, i.e. the space where the electrons interact with the electromagnetic field (fig. 4), is defined by the number of vanes N (which, of course, is also the number of cavities), cathode radius r_c , anode radius r_a and anode height h . A parameter of minor importance in the operation of the magnetron, though of considerable interest to the tube maker, is the thickness t of the vanes.

For fixing the values of the parameters, several general relations are used:

- a) The condition of π -mode operation; in this mode the phase difference $\varphi = k \times 2\pi/N$ of the oscillations of adjoining cavities is equal to π , thus

$$k = N/2. \quad (1)$$

This mode is most favorable for avoiding the excitation of undesired modes (cf. I).

- b) The condition for synchronism between the rotating field and the electrons (I, eq. 5):

$$V = \frac{2\pi}{N\lambda} r_a^2 B \left\{ 1 - \left(\frac{r_c}{r_a} \right)^2 \right\} - \frac{m}{2e} \left(\frac{4\pi r_a}{N\lambda} \right)^2.$$

V is the applied anode voltage, B the flux density of the axial magnetic field, m and e the mass and charge of the electron. This equation can be written as:

$$\frac{V}{V_0} = 2 \frac{B}{B_0} - 1, \quad (2)$$

where

$$V_0 = 10^7 \left(\frac{2r_a}{N\lambda} \right)^2 \text{ volts}, \quad (3)$$

and

$$B_0 = \frac{0.043}{\left\{ 1 - \left(\frac{r_c}{r_a} \right)^2 \right\} N\lambda} \text{ Wb/m}^2, \quad (4)$$

λ and r_a being measured in meters. V_0 and B_0 are the coordinates of the point in the V - B -plane where the straight line defined by (2) is tangent to the cut-off parabola (cf. I, page 50).

²⁾ For this and other concepts used in magnetron operation and design, one is referred to: J. Verweel, Magnetrons Philips techn. Rev. 14, 44-58, 1952 (No. 2). This article is further quoted as I.

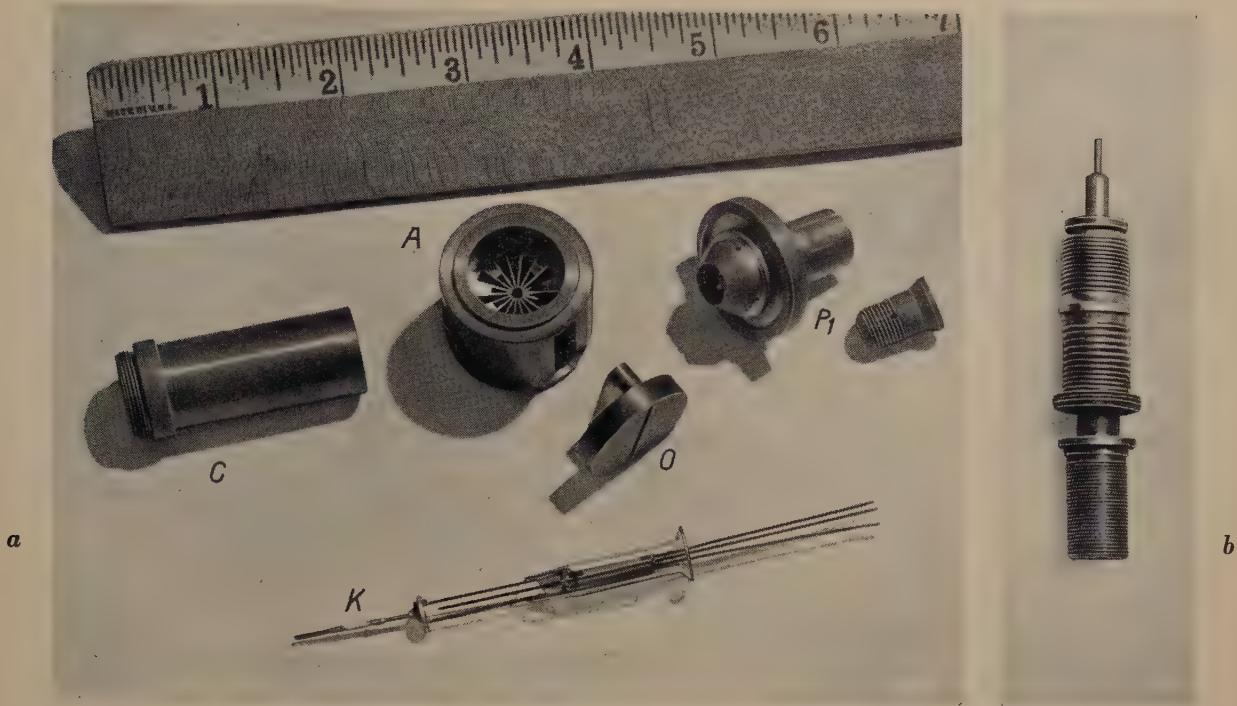


Fig. 3. a) Component parts of the magnetron shown in fig. 2. *K* cathode, *A* resonator system, *O* output transformer, *P*₁ conical pole piece with core for adjustment, *C* container for tuning and temperature compensating device (see later). b) Bellows assembly for tuning and temperature compensating device (see later), on the same scale as (a).

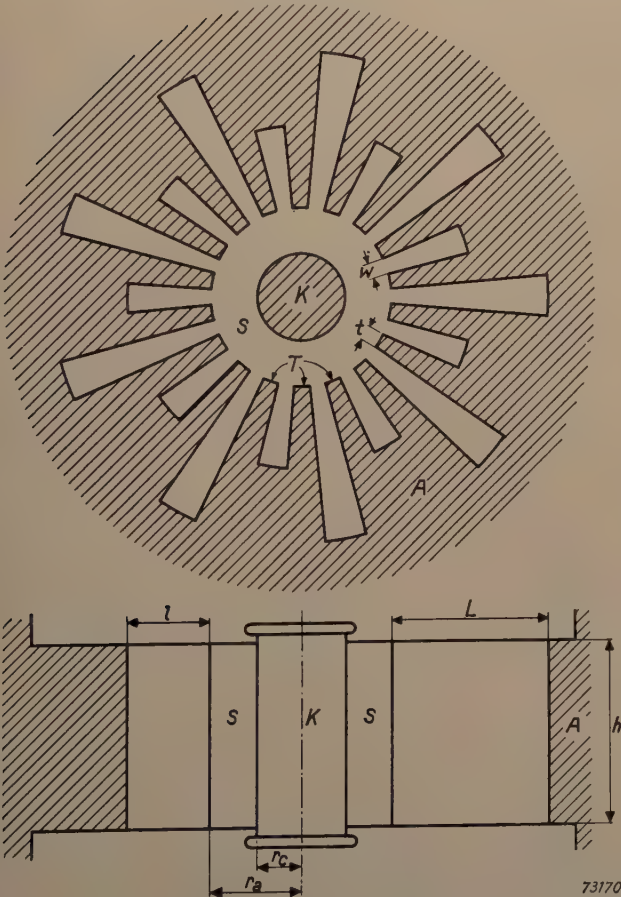


Fig. 4. Cross-section and longitudinal section of rising sun magnetron, showing the interaction spaces, cathode *K* and vanes *T* of anode *A*. *t* vane thickness, *w* slot thickness, *r_c* cathode radius, *r_a* anode radius, *h* anode height.

c) B/B_0 must be sufficiently large in order to obtain a reasonable efficiency (the efficiency is zero at $B = B_0$).

Let us first consider the number of vanes, N . As the magnet is responsible for most of the weight, we cannot afford a large B , hence also B_0 must be small. Therefore, according to eq. (4), N should be large. On the other hand, a large number of vanes means very thin vanes and tiny slots. As the anode system is produced by the hobbing technique (cf. I), both the vane thickness t and the slot thickness w — which is equal to the smallest thickness of the hob projections — should not be too small in order to avoid a mechanical failure of either the hob or the copper block during the hobbing process. A method of reconciling the conflicting requirements of large N and not too small t and w , would be to increase the anode radius r_a , but this would mean that a uniform magnetic field must be provided in a greater volume, necessitating an increase of the magnet weight. From these considerations a number of vanes $N=18$ was chosen as a good compromise, thus making $k = 9$.

At Columbia Radiation Laboratory it was found experimentally that for 18-vane rising sun magnetrons the optimum ratio of cathode to anode radius is given by

$$\frac{r_c}{r_a} = 0,6, \dots \dots \dots (5)$$

yielding for B_0 the value (according to eq. 4):

$$B_0 = \frac{0.043}{(1-0.6^2) 18 \times 0.032} = 0.12 \text{ Wb/m}^2.$$

Now we can proceed to fix the value of B . As noticed before, efficiency increases with B , being zero for $B=B_0$. With a rising sun magnetron, however, a dip in the efficiency occurs at flux density values near $B = 0.0125/\lambda \text{ Wb/m}^2$, i.e. in our case 0.39 Wb/m^2 .

This is explained³⁾ by reference to fig. 5 which shows, at some fixed time, the currents flowing in the resonator walls of a magnetron oscillating in the π -mode. Owing to the rising sun design, the current nodes (and, hence, the places of maximum electric field strength) are not located on the ends

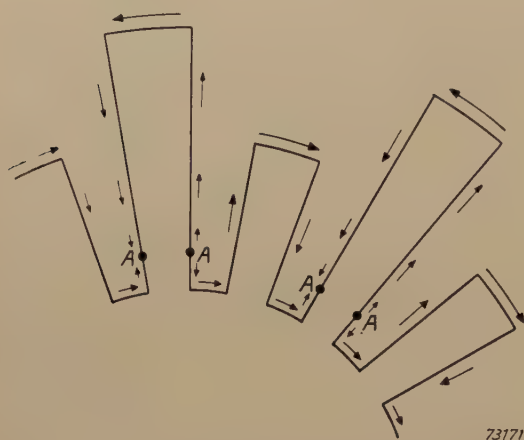


Fig. 5. The arrows indicate the direction and relative magnitude of the currents flowing at a fixed time in the walls of the cavities of a rising sun system. The high frequency current nodes occur at points A inside the larger cavities. (For the explanation of the efficiency dip at $B = 0.0125/\lambda \text{ Wb/m}^2$).

of the vanes but inside the larger cavities, at A . At any moment the currents on all vane ends evidently are flowing in the same direction and, further, the high frequency field strength across the opening of a large cavity is greater than that across the opening of a small cavity. This implies that besides the electromagnetic field characteristic of the π -mode there exists in the interaction space also a field component characteristic of the $k=0$ mode; this is a field varying only with the radius, not with the azimuth angle. Usually this field component does not cause any harm because its effect on each electron that moves away from the cathode on a cycloid path averages zero during the time of interaction of the electron with the π -mode field, in which time the electron describes a number of loops. It will, however, be harmful when the frequency of this rotational movement of the electron, called the "cyclotron frequency" and in the case of a plane magnetron amounting to $\omega=eB/m$, coincides with the desired π -mode frequency. In fact, the periodic radial displacement of the electrons in that case will occur in synchronism with the variation of the $k=0$ field. Thus, when B attains the value

$0.0107/\lambda \text{ Wb/m}^2$, or in the case of the cylindrical magnetron $0.0125/\lambda \text{ Wb/m}^2$, λ being the desired magnetron wavelength in meters, a perturbation of the electron motion occurs, decreasing the efficiency of the interaction with the revolving wave (cf. I). Hence, in the performance chart showing the operating efficiency versus B and V surface, a "valley" will appear along the line $B = 0.0125/\lambda$ („valley of shadows").

It is, therefore, desirable to operate either above or below this flux density value. Since the magnet weight was of prime importance, it was decided to operate below the dip, at $B = 3B_0 = 0.35 \text{ Wb/m}^2$, making a good compromise between efficiency and weight.

The remaining parameters are now easily found. Eq. (2) yields

$$\frac{V_0}{V} = 5,$$

and for $V = 800 \text{ V}$, we must choose $V_0 = 160 \text{ V}$. From (3), r_a is obtained:

$$r_a = 1.15 \text{ mm},$$

and from (5) it follows that

$$r_c = 0.69 \text{ mm}.$$

The circumference of the interaction space is $2\pi r_a = 18t + 18w$. The thickness t and w of vanes and slots were chosen equal, in order to facilitate the hobbing. Hence:

$$t = w = 0.20 \text{ mm}.$$

This is a practicable value, though it will be clear that both the hob and the anode system will have to be handled with care.

The anode height h defines the necessary gap length of the magnet and the required emission density of the cathode. From experience with other magnetrons, an anode height of 5.08 mm was selected.

The cathode

In order to obtain 100 W output at 30% efficiency with 800 V anode voltage, a current I of 0.417 A is needed. The required emission density is:

$$J = \frac{I}{2\pi r_c h} = 1.9 \text{ A/cm}^2.$$

This is a reasonable value for a pulsed cathode with a duty cycle of 0.003 .

The heating power limitation is severe and a type of cathode of the highest thermal efficiency must be adopted, especially since in this low power tube heating of the cathode by back-bombardment is negligible. A normal oxide-coated cathode heated

³⁾ See J. B. Fisk, H. D. Hogstrum and P. L. Hartman, Bell Syst. techn. J. 25, 167-348, 1946, especially p. 230.

by a single tungsten helix coated with aluminum oxide, with a rating of 6.3 V, 290 mA, meets the specifications. The rigidity and concentricity of the cathode (fig. 3, K) is ensured by supporting it axially between ceramic spacers, which are firmly seated in the recessed pole pieces.

Before proceeding to discuss the other parts of the design, it may be interesting to make a comparison between this low power tube and a high power pulsed magnetron for radar.

Let the power of such a radar magnetron of 3 cm wavelength be 1 MW. A normal efficiency value for these magnetrons is 50%. The input power, then, is $V \times I = 2$ MW. As it is known that the ratio V/I , i.e. the impedance of the magnetron, cannot be decreased to a value lower than 300-400 ohms, the required D.C. voltage and current are

$$V \approx 30 \text{ kV,}$$

$$I \approx 70 \text{ A.}$$

For 18 resonators, $r_c = 3$ mm and $r_a = 5$ mm are suitable values in this case. Calculating from these values, we obtain $V_0 = 3$ kV and $B_0 = 0.115$ Wb/m², yielding $V/V_0 = 10$ and by virtue of eq. (2):

$$B = 5.5 B_0 = 0.64 \text{ Wb/m}^2,$$

the flux density thus being above the efficiency dip.

Given the current $I = 70$ A and a practicable emission density J of 18 A/cm², the required anode height is found to be $h = 20$ mm.

As compared with our beacon magnetron, the design characteristics of the radar magnetron may be summed up as follows:

- 1) 17 times larger cathode surface and 10 times larger current density, making the total current about 170 times that of the beacon magnetron.
- 2) About 4.5 times larger anode radius r_a , entailing a higher V_0 -value, and larger ratio V/V_0 , both leading to a voltage higher by a factor of about 40.
- 3) The volume of the interaction space, and hence also the volume in which the uniform magnetic flux density must be established ($\pi r_a^2 h$), is about 75 times that of the small magnetron. Together with the larger flux density value (which results in the higher efficiency), this necessitates a total magnetic energy and a weight of magnet steel about 150 times that of the beacon magnetron!

The dimensions of the resonators and the output system

The dimensions of the resonators that remain to be fixed are the lengths L and l of the large and small cavities respectively (fig. 6).

The sum $L+l$ is determined by the desired wavelength. In fact, omitting a correction factor whose value is not far from unity, the wavelength can be put equal to the total perimeter of a large and a small cavity as indicated by the heavy line in fig. 6. The ratio L/l then must be chosen. A large value of L/l enhances the mode separation, but unfortunately also favors the $k = 0$ mode contamination (des-

cribed in the small print text on page 90), and therefore diminishes the efficiency as the B -range having a reduced efficiency is widened. Thus a compromise will be necessary.

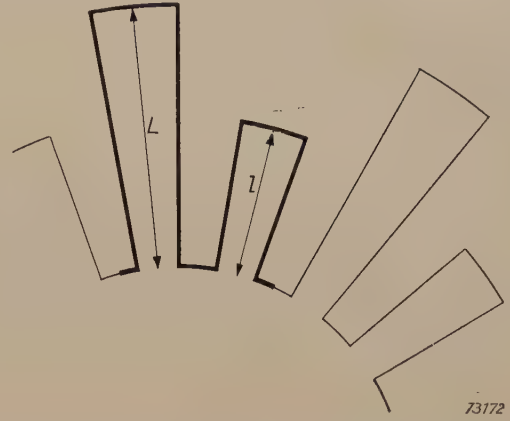


Fig. 6. The total perimeter $2L+2l$ of one large and one small cavity (heavy line) differs but little from the wavelength of the π -mode oscillation.

An explanation of the exact way in which the ratio L/l is selected and the correction factor for the sum $L+l$ is determined, falls beyond the scope of this article, as well as the design of the details of the output system (transformer-waveguide section): this must be designed to keep the pulling figure within the required limit of 6 Mc/s and at the same time to give the highest possible efficiency. It should only be said that the design procedure is akin to that used in the previous part of the article and to those generally applied in magnetron design: the theoretical analysis is used as far as possible, but up to the present time the theory is inadequate, i.e. it cannot predict whether or not a chosen model will operate satisfactorily: therefore, a set of dimensions is chosen from experience gained with other magnetrons of similar specifications. A model can then be built and tested, and from the result of such tests the modifications that may be necessary are derived.

In this way we obtained the value $L = 7.4$ mm and $l = 4.25$ mm, and a transforming section was developed, consisting of a rectangular slot of cross-section $22.3 \text{ mm} \times 11 \text{ mm}$ and length 10.8 mm (fig. 3, O).

The magnet

Owing to the very small interaction space, only a small magnetic energy is needed, thus providing the possibility of considerable saving in magnet weight. In designing the magnet, however, several conditions must not be neglected. The magnetic field should be essentially uniform in the entire interaction space in order to prevent electrons from spiral-

ling out to the magnet pole pieces. The vacuum gap between the pole pieces — for which it would be desirable not to exceed the anode height — must be made long enough to avoid any electrical resonances

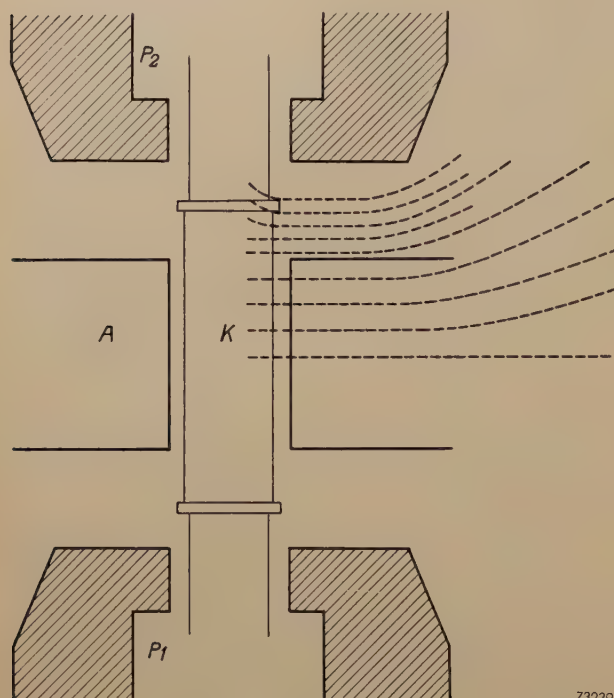


Fig. 7. Longitudinal section of the 3 cm-magnetron with pole pieces P_1 , P_2 of the magnet. Axial holes in the pole pieces permit mounting and rigid supporting of the cathode. The broken lines indicate the "equipotential surfaces" of the magnetic field, which is seen to be quite uniform in the interaction space.

of the end spaces, as these can lead to mode instability and loss in efficiency. The ultimate design consists of two conical pole pieces with a gap of 7.62 mm (fig. 3, P_1), the magnetomotive force being provided by a horseshoe magnet of weight 600 g (fig. 2). Fig. 7 is a scaled drawing of the longitudinal cross-section of the system together with the pole pieces. In this figure the "equipotential surfaces" between pole pieces as obtained from an electrolytic tank ⁴⁾ are indicated, the magnetic lines of force being perpendicular to these surfaces. It will be seen that the field is quite uniform in the entire interaction space between anode and cathode.

Tuning

The required tuning range, from 9300 to 9320 Mc/s, is small enough to be realized by tuning in a single anode resonator rather than in all resonators, which of course greatly simplifies the construction.

⁴⁾ M. Bowman-Manifold and F. H. Nicoll, Electrolytic field plotting trough for circularly symmetric systems, Nature 142, 39, 1938.

Two methods of tuning were investigated experimentally. In the first method a pin is introduced through one of the anode end spaces into the open side of one cavity (fig. 8a). A spurious resonance was noticed at one particular pin position, causing a marked efficiency dip and making this method unusable. In the other method, a pin is introduced radially into one cavity (fig. 8b). Experiments carried out with a non-oscillating tube indicated that the quality factor Q of the resonant system was not radically affected through a useful range of tuning. Either the small or the large resonator could be used for inserting the pin; we chose the latter.

The frequency increases as the pin is inserted; the frequency change per unit insertion and, therefore, the total frequency range varies with the cross-sectional area of the tuning pin. The frequency range obtained with three different pins and a radial motion of 2.54 mm is given in table I. The largest tuning pin, offering a range of 80 Mc/s, did not seem to affect the operating characteristics of the tube, although it decreased the efficiency slightly. In fabricating the tubes, the frequency will be found to differ slightly from tube to tube. It is, therefore, desirable to have a large tuning range so that the nominal frequency with the required range will be covered in every case. For this reason we chose the largest pin of table I.

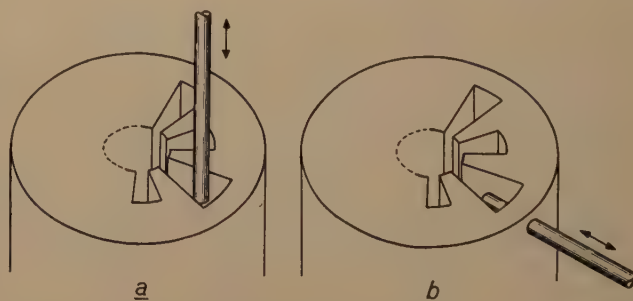


Fig. 8. Two methods of tuning the magnetron.
a) A pin is introduced through one end space into one of the open sides of a cavity.
b) A pin is introduced radially into a cavity.

Table I. Tuning range obtained with different pins and a radial motion of 2.54 mm.

Cross-section of pin	Frequency range Mc/s
Circular, 1.52 mm diam.	12
Rectangular, 1.52 mm × 3.2 mm	65
Rectangular, 1.52 mm × 4.56 mm	80

Temperature compensating device

In the temperature range through which the tube was required to operate the frequency was found to vary 0.16 Mc/s per °C due to the thermal expansion of the anode block. The permissible frequency variation is 3 Mc/s over 40°, i.e. 0.075 Mc/s per °C.

frequency by expanding the resonance cavities of the magnetron, will cause the liquid in the bellows *D* to expand comparatively strongly, while the cylinder *E* with sleeve *F* (apart from its own, smaller, expansion) maintains its position. In this case the bellows *D* will be lengthened and the pin (*B*) will

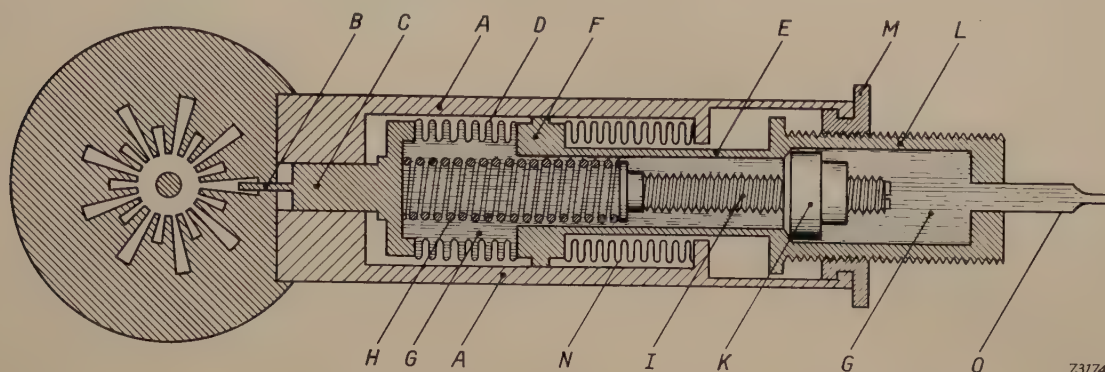


Fig. 9. Schematic drawing of tuning mechanism combined with temperature compensating device. *A* container, *B* tuning pin, *C* plunger, *D* and *N* bellows, *E* cylinder with sleeve *F*, *G* liquid, *H* pulling spring fastened to plunger *C* and pin *I*, *K* retaining nut (fluted), *L* screw, *M* knurled washer, *O* pinched-off filling tube.

It was, therefore, necessary to incorporate a temperature compensating device in the tube. This device was combined with the tuning mechanism in a novel way.

A schematical drawing illustrating the device is presented in *fig. 9* (cf. also *fig. 3b*). The mechanism is housed in a cylindrical container (*A*) brazed vacuum-tight to the anode axis. The tuning pin (*B*) is an integral part of a plunger (*C*) connected to vacuum-tight bellows (*D*). The other end of these bellows is soldered to the end of a cylinder (*E*) with retaining sleeve (*F*) sliding inside the container (*A*). This cylinder *E*, which is closed at its other end, and the bellows *D* are filled with a liquid (*G*) at atmospheric pressure. As the space outside the bellows *D* is evacuated, the bellows are secured against undue expansion by means of a pulling spring (*H*) fastened to the plunger (*C*) and to a pin (*I*) retained by a fluted nut (*K*).

Tuning is effected by means of a screw (*L*) and knurled washer (*M*). When the washer is turned, the whole assembly of cylinder *E* with bellows *D*, spring and plunger will move, say, to the left, thereby inserting the tuning pin in the resonant cavity and increasing the magnetron frequency. On the other hand an ambient temperature increase, which lowers the

again be inserted in the cavity, effecting a compensating increase of the frequency of the tube.

The second bellows (*N*) visible in *fig. 9* serve no other purpose than to provide in the conventional fashion a vacuum-tight seal of the cylindrical container *A* and, hence, of the magnetron; they are necessary because the sliding sleeve *F* cannot be expected to provide a vacuum-tight seal. It should be noted that on tuning, bellows *D* retain their length while bellows *N* are expanded or compressed,

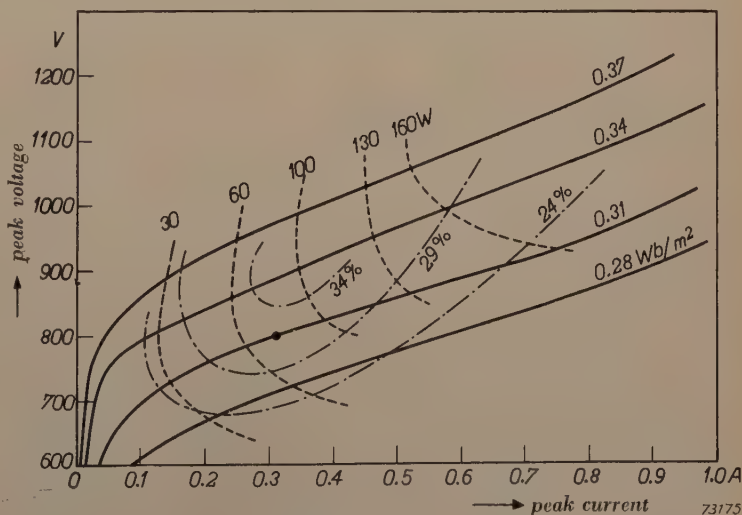


Fig. 10. Performance chart of one of the final models of the magnetron PAX3, for a duty cycle of 0.0005 (pulse width 5×10^{-7} sec, repetition rate 1000 per second). The point marked by a small circle corresponds to voltage 800 V, field 0.31 Wb/m², efficiency about 30%.

whereas on compensating temperature variations the roles of the bellows are reversed.

Filling the inner volume with liquid is effected through a copper tube (O) which then is pinched off. By selecting a liquid with a proper thermal expansion coefficient, a very satisfactory temperature compensation can be achieved. Of course, the liquid

must meet additional requirements; above all it must not chemically attack the parts with which it is in contact. For the same reason it must be absolutely free of water. Of the various liquids tried, only two proved to be satisfactory, namely, hexane and 2,2,4-trimethylpentane. The former was chosen and a temperature coefficient of the magnetron of 0.075 Mc/s per °C was obtained between the limits of -50 to +50 °C, in accordance with the specifications.

To conclude this short description, the performance chart (cf. I) of one of the final tube models is shown in fig. 10. It may be seen that the magnetron will operate satisfactorily at 800 V and at a magnetic field of 0.31 Wb/m², with an efficiency of nearly 30%. Fig. 11 is the Rieke-diagram (cf. I); the pulling figure is seen to be approximately 6 Mc/s, in accord with the specification. The total weight of this model including the magnet, is 1080 g.

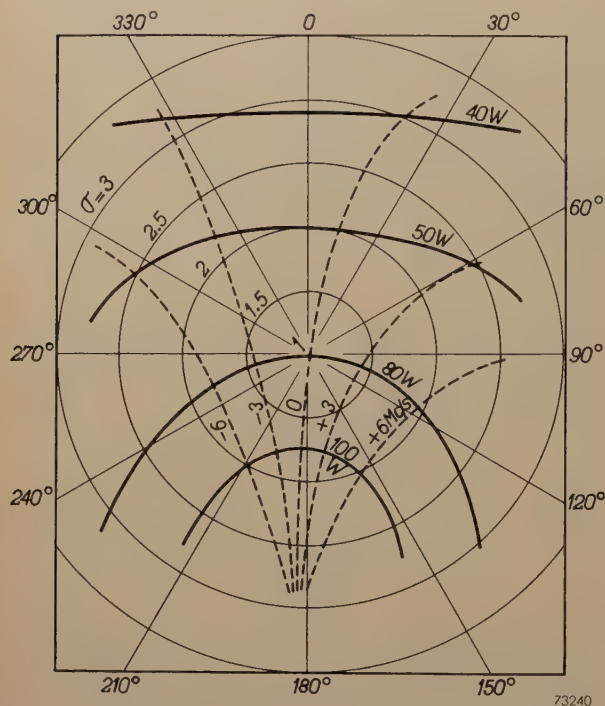


Fig. 11. Rieke-diagram of the same model as in fig. 10. Pulling figure (total frequency variation encountered on the broken lines when making one complete revolution along the circle of voltage-standing-wave-ratio $\sigma = 1.5$), is approximately 6 Mc/s.

Summary. The development described concerns an 18 vane rising sun type magnetron for 3 cm waves especially designed for beacons. The nominal peak power output is about 100 W, the frequency is variable by about 20 Mc/s, the frequency stability meets very exacting requirements, owing to the incorporation of a novel temperature compensating device. This device is combined with the tuning mechanism, based on the radial insertion of a pin into one of the 18 resonant cavities: an expanding liquid hydraulically moves the plunger carrying the tuning pin, thus compensating the temperature drift of the tube frequency. Other typical properties are: low anode voltage (800 V), low cathode heater rating (6.3 V, 300 mA) and small weight (1080 g, including the magnet). The considerations enabling a suitable design of the interaction space, the resonators, the magnet and other parts of the tube are expounded and some stress is laid on the limits of the theory and on the part played by experimental study in magnetron development.

RADAR STATION AT IJMUIDEN (HOLLAND)



The 75th anniversary celebrations of the North Sea Canal, held recently, have been graced by the opening of a radar station, the first harbour radar station in continental Europe.

The installation is housed in the semaphore building at IJmuiden. The rotating aerial (a parabolic reflector) is mounted on the roof of the building. The wavelength is approximately 3 cm, and 3000 pulses are transmitted per second with a peak power of approximately 7 kW.

The photograph shows the radar panorama as it appears on the receiving screen. The photograph may be compared with the attached transparency, which is a chart of the same harbour area. The short white line just outside the piers is a ship.

When the photograph was taken, the scale of the radar image was 1 : 20 000 (that of the illustration is 1 : 22 500). Other scales may be selected, i.e. 1 : 11 000 and 1 : 57 000. In the latter case an area with about 6 miles radius is covered.

The installation was built by Philips Telecommunication Industries, Hilversum, in co-operation with N.V. Van der Heem, Voorburg (Netherlands).

LOW-HYDROGEN WELDING RODS

by J. D. FAST.

621.791.753.4

With the progress of engineering, welded joints in metal constructions have reached much higher standards. This involved the development of welding rods which yield but little oxygen to the weld metal. However, if no special precautions are taken, decrease of the undesirable oxygen content will lead to an unwanted increase in the hydrogen content. A new type of electrode, the so-called "low-hydrogen" welding rod, has therefore been developed.

Influence of the coating of the electrode on the gas content of the deposited metal

In most countries of the world only coated electrodes are used for electric arc welding, particularly for welding in air. The chief function of the coating is the protection of the molten metal from the oxygen and nitrogen in the air. Its second and nearly as important function is the evolution of sufficient gas for the globules, developed during the welding process at the end of the electrode, to be driven out with great force, giving rapid transfer of the metal to the work piece and good penetration (even in the case of "overhead" welding).

The coating of electrodes always contains metal oxides. Should these metal oxides easily yield large quantities of oxygen to the molten metal, the above-mentioned favourable function of the coating, viz. that of protecting the metal from oxygen (and nitrogen attack) would be illusory. By using very stable oxides only and by adding reducing metal powders to the coating, the latter was improved to the point of yielding a minimum quantity of oxygen to the weld metal. However the greater the success in combating the evil of oxygen absorption, the nearer becomes the incidence of another nuisance, viz. the absorption of considerable quantities of hydrogen.

The combination of compounds contained in the coating of an electrode releases water vapour on heating. This water vapour enters the arc atmosphere and is in contact with the molten metal during the welding process. Hydrogen and oxygen being soluble in this metal to a certain extent, the following equilibrium is ultimately approximated:



The square brackets indicate the hydrogen and oxygen in the metal in the dissolved state. (H and O have been used as symbols instead of H_2 and O_2 because hydrogen and oxygen are present in the metal in the atomic and not in the

molecular state). In equilibrium — depending on the temperature T — a simple relationship holds approximately, between the percentages of hydrogen and oxygen in the metal and the pressure $p(\text{H}_2\text{O})$ of the water vapour outside. This relationship is the following:

$$\frac{[\% \text{H}]^2 \times [\% \text{O}]}{p(\text{H}_2\text{O})} = C(T) \dots (2)$$

showing that the smaller the oxygen content of the metal and the larger the pressure of water vapour, the larger is the hydrogen absorption by the metal¹).

It is indeed a fact that on improvement of the electrode coatings with regard to the release of oxygen to the metal, the hydrogen absorption by the metal increased automatically at an unchanged water vapour content of the arc atmosphere. This was attended by various disagreeable phenomena.

Detrimental action of hydrogen

Hydrogen is absorbed by the molten metal during the welding process. The solubility of hydrogen in iron diminishes with decreasing temperature; at the solidification point it even drops abruptly. Thus the absorbed hydrogen will be partly released again during the cooling process. If the metal is still liquid the excess gas can leave it in two ways:

1) gas bubbles may form in the liquid metal and rise to the surface under the influence of the hydrostatic pressure;

2) the atoms may diffuse to the outer surface and recombine to form molecules.

We have already discussed extensively in this review the effect of these two processes on the welding process itself. In some circumstances, e.g. when relatively large quantities of sulphur are present in the metal, the formation of gas bubbles during the cooling process may cause porosity of the weld.

¹) The state of equilibrium to which formula (2) is applicable is never completely attained during the welding process. Nevertheless the formula will be useful for the following semi-quantitative discussion.

The article cited under ²⁾ gives more details on the influence of sulphur.

As soon as the deposited metal has completely solidified, further release of hydrogen can only be effected via the second process: diffusion of hydrogen atoms through the metal and subsequent recombination at the surface to molecules. The thicker the metal from which the gas is to be released and the lower the temperature ³⁾, the longer the diffusion process will take. Hence if the metal to be welded is very thick, a large quantity of hydrogen will be retained, in the first place owing to the long distance the atoms have to travel in the diffusion process and in the second place by the rapid cooling caused by the thickness of the metal. In this second process, as in the first one, the presence of sulphur may retard the release of hydrogen still more ⁴⁾.

The excess hydrogen, left in the metal after the cooling process, can collect under very high pressure in molecular form in internal microscopic or sub-microscopic voids. The following may serve to explain this ⁴⁾. Let us suppose solid iron in equilibrium with hydrogen of 1 atmosphere at 1520 °C to cool down so rapidly to room temperature that no hydrogen at all is released. At the temperature of 1520 °C about 14 cm³ hydrogen was dissolved in the atomic form in every hundred grams of iron. At room temperature less than 0,1 cm³ hydrogen is present in this form per 100 grams of iron in the equilibrium state (with hydrogen at 1 atm outside the iron). However, 14 cm³ hydrogen are actually still present in the iron after quenching and this corresponds to an external equilibrium pressure of more than 20 000 atmospheres.

The rate of diffusion of hydrogen in iron is still relatively high at room temperature; a considerable quantity of hydrogen will be released after recombination at the outer surface ⁵⁾. This process of recombination to molecules will also take place at the surface of each small cavity or included piece of slag in the interior of the metal. Most important of all: at low temperatures the process does not take place at a perceptible rate in the reverse direction since only atoms can diffuse through the metal and since dissociation of hydrogen molecules at the surface is a very slow process at low temperatures. As long

as the metal is supersaturated with hydrogen the diffusion to the cavities will proceed, even if the pressure in the cavities rises to very high values. In the case under discussion this pressure can increase to thousands of atmospheres. Welding with normal types of electrode may therefore be expected to lead to the building up of large pressures of hydrogen in tiny voids within the weld. Consequently test bars made from the metal of such a weld show so-called fish-eyes on the surface of fracture (fig. 1). These fish-eyes show

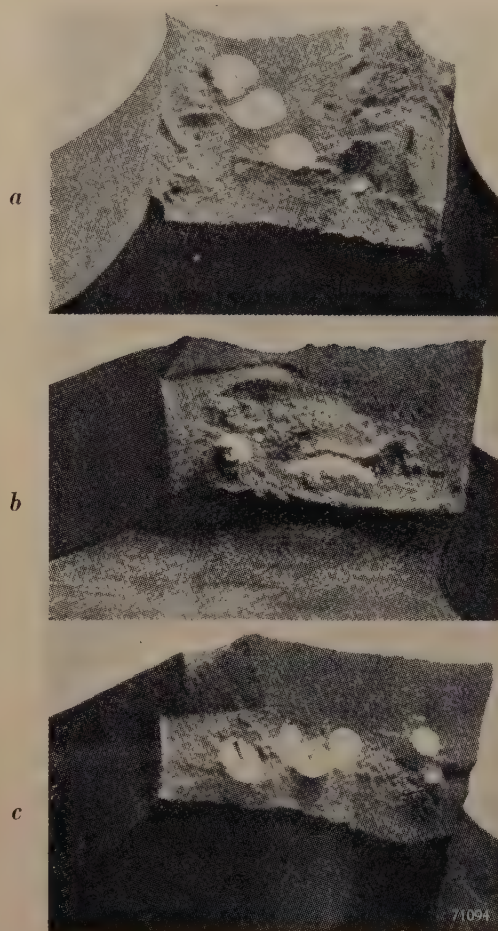


Fig. 1. Fish-eyes on the surface of fracture of test bars, made from weld metal, caused by the metal containing a) gas bubbles b) coarse slag inclusions c) finely divided inclusions. (H. Bennek and F. H. Müller, Arch. Eisenhüttenwesen, 14, 605-615, 1940/41.)

minor holes or inclusions in their centre. In these regions the metal could not deform plastically because of the high hydrogen pressure and the stresses developing during the elongation. During the deformation of the test bar this results in brittle fractures on a very small scale in these regions. It was found that the pressure in the micro voids only increases to dangerously high values during the elongation. Hence fish-eyes can only

²⁾ J. D. Fast, Causes of porosity in welds, Philips techn. Rev. 11, 101-110, 1949.

³⁾ This holds good for iron in only one modification e.g. ferrite, for in austenite the rate of diffusion of hydrogen is smaller.

⁴⁾ J.D. Fast, Hydrogen in arc welding, Lastechiek 15, 220-224, 1949 (in Dutch).

⁵⁾ If a newly made weld is immersed in water, in many cases small gas bubbles will be formed at the surface for a long time.

be formed after much larger deformation than ever occurs in a construction, and therefore cannot adversely influence the strength of the welded joint.

What is much more serious, the presence of much hydrogen under very unfavourable conditions may lead to cracking in or near to the weld. This may happen with electric welding when the carbon content of the steel to be welded is very high. These cracks near the weld can be accounted for as follows: In the region of the weld the metal is heated to the austenite range (γ -iron range) during the welding process; the subsequent rapid cooling can give rise to the formation of martensite⁶⁾ (carbon-containing body-centred cubic iron with tetragonal deformation). The attendant changes in volume may in their turn cause the development of cracks of microscopic size. High hydrogen pressures may develop in these cracks unless electrodes of the low-hydrogen type are used, and these may grow into macroscopic cracks in the relatively brittle region around the weld.

Hydrogen may also contribute to cracking of the still hot metal of the cooling weld itself (so-called "hot-cracking")⁷⁾. Further discussion of this subject in the present paper would lead us too far.

Coating of some types of electrodes

It is evident from the preceding sections that the water content of the coating has increased in importance with the decrease of the oxygen transmitted by the coating to the metal. We shall go somewhat deeper into the problem by discussing the chief types of electrodes. They are respectively:

- 1) The bare electrode.
- 2) The dead - soft electrode (completely inorganic coating, chiefly consisting of iron oxides, carbonates and silicates).
- 3) The mineral-coated electrode with ferromanganese and ferro-silicon added to the coating.
- 4) The organic electrode containing i.a. large quantities of TiO_2 (rutile), although its most characteristic constituents are certain organic compounds.
- 5) The basic or low-hydrogen electrode, to be discussed later in this paper.

The two first-mentioned types of electrodes (the bare electrode and the dead-soft electrode) are hardly used any more nowadays. With the exception of the last type (the low-hydrogen electrode) all

coated electrodes contain substances, e.g. water-glass and organic compounds, which evolve relatively large quantities of water vapour during the heating process. Starting from the equilibrium formula (2), we shall try to compute the hydrogen content of the metal deposited by the various types of welding rods. To do this we shall have to know in the first place the value of the constant $C(T)$ from formula (2) for about 1540 °C, i.e. at a temperature just above the melting point of iron (1539 °C). We have pointed out in another paper⁸⁾ that at this temperature:

$$C = 1.1 \times 10^{-6},$$

if the water vapour pressure is given in atmospheres and the hydrogen and oxygen content of the metal in weight percent by. Moreover, we shall need two experimental values for each type of welding electrode, viz. the water vapour content of the arc atmosphere and the oxygen content of the liquid metal.

With regard to the latter a difficulty arises because the metal to be welded also contains silicon and manganese, which have a great affinity for oxygen and thus lower the activity of this element in the molten metal. We shall get an upper limit for the hydrogen absorption of the molten metal if we only take into account that percentage of oxygen which on chemical analysis of the deposited metal is found in the form of FeO . On the other hand a lower limit for the hydrogen absorption will be found if the percentage substituted in formula (2) is the total analytically found oxygen content. However, the latter value should never exceed the saturation content of the molten metal at 1540 °C, viz. 0.2% O. Even if more oxygen has actually been absorbed, we should never substitute a greater value since the surplus is not present in the dissolved state, whereas the quantity [% O] in the formula only refers to this state. As a matter of fact the metal absorbs more oxygen than corresponds to the solubility in molten iron if bare electrodes are used (the surplus as an oxide).

We have, basing ourselves on the experiments of Mallett and Rieppel⁹⁾, substituted in the formula a value of 0.2 atm for the partial water vapour pressure in the arc atmosphere for all coated electrodes except the low hydrogen one. For bare electrodes the water vapour content is at the utmost equal to that of the atmosphere, viz. only about

⁶⁾ For a discussion of the arrangement of the atoms in the various modifications of iron we may refer e.g. to J.D. Fast, Ageing phenomena in iron and steel after rapid cooling, Philips Techn. Rev. 13, 165-171, 1951 (No. 6).

⁷⁾ P. C. van der Willigen, Lastetechnik 15, 317-321, 1949; Berg- und Hüttenmännische Monatshefte 95, 234, 1950.

⁸⁾ J. D. Fast, Philips Research Reports 5, 37-45, 1950.

⁹⁾ M.W. Mallett, Welding J. 25, 396S-399 S, 1946; M. W. Mallett and L. J. Rieppel, Welding J. 25, 748S-759S, 1946.

0.01 atmosphere. The same low partial pressure was entered in formula (2) for the low hydrogen electrode. We shall discuss this later.

The following *table* gives both the total oxygen percentage and the oxygen present as FeO for the deposited metal of the above mentioned types of electrodes. A third experimentally found content is given, viz. the hydrogen content of the deposited metal. Moreover, the table contains the lower limit of the hydrogen content calculated with the aid of formula (2) (see above).

Hydrogen and oxygen contents of the deposited metal.

Type of electrode	Experimentally found contents			Lower limit of the hydrogen content according to formula (2)	
	weight % O total	weight % O as FeO	weight % H	weight % H	cm ³ H ₂ per 100 gr. iron
bare	0.25	0.25	—	0.0002	2.5
“dead-soft”	0.20	0.20	—	0.0010	11.5
“mineral-coated”	0.12	0.04	0.0015	0.0013 ⁵	15
“organic”	0.06	0.004	0.0020	0.0019	21
“low-hydrogen”	0.03	0.001	0.0007	0.0006	6.5

Computation of an upper limit of the hydrogen content in the above-mentioned manner gives values for the two last types of electrodes that correspond to hydrogen pressures considerably higher than 1 atm. In these cases, therefore, calculation of an upper limit would have to be carried out in a slightly different manner. It would lead us too far to discuss the problem more extensively in this paper.

It will be noted that there is fair agreement between the experimentally found values and the calculated lower limits of the hydrogen content. This agreement is surprising since our calculations are but rough. We have not only based ourselves on an assumption which only holds good on approximation, viz. that a state of equilibrium is reached during welding, but — what is of more importance — we have neglected two most important factors, viz. the release of a considerable quantity of hydrogen during the solidifying and cooling process and the absorption of a large quantity of hydrogen in excess of the above calculated lower limit under the influence of silicon and manganese present in the metal. The two faults in our computation apparently counterbalance each other. As a matter of fact the experimentally found hydrogen contents exceed the figure given in the table if the cooling process is extremely rapid, whereas abnormally slow cooling results in smaller hydrogen contents.

It is evident from the table that the improvement of the quality of the weld metal by reducing the oxygen content was at first obtained at the cost of an increase of the hydrogen content. A high oxygen content is so unfavourable that bare electrodes are no longer used in most countries, although the welds produced by using these electrodes have a very low hydrogen content; dead-soft electrodes are only applied when a fine appearance of the bead is of more importance than its mechanical strength. All things considered, the two next types of electrodes, the mineral coated electrode (e.g. the Philips electrodes 50 and Contact 20) and the organic electrode e.g. the Philips 68 and Contact 18 are important improvements on the two preceding electrodes, but the hydrogen content of the deposited metal has risen to a relatively high level (especially if the organic electrode is used).

With basic electrodes, e.g. Philips electrodes 36 and 56, a weld can be made containing both little oxygen and little hydrogen. Therefore the use of these more expensive electrodes is often economically justified. We shall now proceed to a discussion of the way in which the favourable properties of these electrodes are obtained.

The low-hydrogen electrode

In principle the oxygen content of the weld metal can be lowered by choosing an electrode coating that produces a slag containing no oxides at all or only very stable oxides. The use of iron oxides should be avoided in the first place. Good results can be obtained with a mixture of stable oxides and fluorides; their proportion in the mixture should be such that the quantity of nitrogen transmitted to the metal is also small¹⁰⁾.

For the weld to have as low a hydrogen content as possible only little water vapour should be evolved by the coating during the welding process. At first sight, one would suppose that this requirement could easily be met by heating the electrodes before the welding process to a temperature that is high enough for all the chemically bound water to be driven out. However, such a thermal treatment tends to make most electrodes unfit for use since it considerably reduces the development of gas during the welding process; we have already observed that adequate evolution of gas is of primary importance. Moreover, the heat treatment as a rule reduces the mechanical strength of the coating to such a degree that the electrodes can no longer be transported.

¹⁰⁾ Cf. J. D. Fast, Philips techn. Rev. 10, 114-122, 1948.

However, all requirements can be met by:

a) using a coating containing a carefully chosen mixture of substances that evolve gases containing no hydrogen. b) by a well chosen thermal treatment of the electrodes before delivery. Since chiefly basic oxides are used in the coating, these low-hydrogen welding rods are often called basic electrodes.

Low-hydrogen electrodes manufactured and treated in the way described yield only very little

Use of low-hydrogen electrodes

On the practical application of non-basic electrodes it appears that their hydrogen content causes no difficulties at all in a great number of cases when normal unalloyed steel has to be welded. Low-hydrogen electrodes compare favourably, however, as soon as circumstances arise in which it is difficult for the hydrogen to escape from the metal e.g. if the steel contains large quantities of sulphur



Fig. 2 A great welded project in the open air, the catalytic cracking installation of the "Bataafse Petroleum Maatschappij" at Pernis, a subsidiary of the Royal Dutch Company. This plant, with a capacity of 3500 tons high octane petrol a day, was completely welded with low-hydrogen electrodes type Philips 36. The number of electrodes used amounted to about four million.

hydrogen during the welding process; the water vapour pressure in the arc atmosphere is as low as in that of bare electrodes, viz. about 0.01 atm; according to formula (2) this corresponds to the low hydrogen content of the weld of 6.5 cm³ per 100 grams of iron, already given in the table. The various difficulties caused by hydrogen are no longer observed if these electrodes are used.

or if the material is relatively thick (although in the latter case preheating the metal may sometimes prevent dangerously high hydrogen concentrations during the welding process when using non-basic electrodes).

Care should be taken that low-hydrogen electrodes do not lose their good qualities by absorption of water vapour from the atmosphere by inadequate

storage. Zoethout¹¹⁾ tried out three simple methods to guarantee a sufficiently dry atmosphere in the storage room for low-hydrogen electrodes:

- 1) Keeping the temperature in the storage room permanently at least 10 °C higher than the outdoor temperature.
- 2) Placing containers filled with hygroscopic substances in the storage room.
- 3) Continuously conveying dried and heated air into the storage place.

In practice each of these methods proved to be sufficient.

When welding in the open air, a storage place that comes up to one of the three above-mentioned requirements will in most cases not be available. The following procedure was therefore adopted when the large project shown in *fig. 2* had to be carried out in the Netherlands. The basic electrodes were delivered in boxes by the Philips welding rod

factory to the unheated storeroom; these boxes were at once placed in tins which were sealed with gummed tape. Packed in this way the electrodes could be stored without any deterioration in quality. Naturally, after a box was opened, some of the electrodes were in contact with the open air for several hours. However, the moisture absorbed by the welding rods during this period was never sufficient, not even when there was a thick fog, for poor hydrogen-characteristics to develop during the welding process.

Summary. Nowadays coated welding rods are almost exclusively used for electric arc welding. The coating should transmit little oxygen (and nitrogen) to the metal during the welding process, since otherwise bad quality welds are obtained. Suppression of the oxygen transmission causes absorption of large quantities of hydrogen if non-basic welding rods are used. In unfavourable circumstances this may give rise to porosity and cracking of the weld. In order to decrease the hydrogen content, the welding rod should contain as little water as possible. Basic or low-hydrogen electrodes were developed to meet this requirement. For these electrodes to keep their favourable properties, they have to be stored in a special way.

¹¹⁾ G. Zoethout, *Lastechniek* 17, 126-128, 1951.

AN INSTRUMENT FOR MEASURING COMPLEX VOLTAGE RATIOS IN THE FREQUENCY RANGE 1-100 Mc/s

by G. THIRUP.

621.317.34:621.396.645

In the early days of amplifier technique, flatness of the gain-frequency curve over the audio frequency range was considered a reliable criterion of the satisfactory transmission of speech and music. Later, however, with the advent of pulse and television transmission, it was found that a flat gain-frequency characteristic was insufficient to ensure conservation of the waveform of the signal. Moreover, the present wide-spread use of negative feedback in amplifiers necessitates a convenient method of investigating the stability of such amplifiers. The measurement of the complex ratio of two voltages is an essential step in both these techniques.

The instrument described, with which such ratios can readily be measured, was designed specially for the investigation of amplifier stability, over a much wider frequency range than has hitherto been possible. It is intended for research work in the Philips Laboratories and is not commercially available.

A communication system generally consists of a signal source, a transmission system and a load represented by a terminating impedance. The transmission system — assumed to be linear — is characterized by the ratio between an applied sinusoidal input voltage and the corresponding output voltage. This ratio is, in general, complex and a function of frequency. The numerical value, or modulus, of the ratio is easily measured by means of voltmeters or by inserting a calibrated variable attenuator and reducing the ratio to a datum value. For many purposes a gain-frequency characteristic measured in one of these ways is sufficient information. In other cases, however, it is essential to know the phase difference between the input and output voltages, as a function of frequency.

The necessary and sufficient conditions to ensure the conservation of the waveform of an arbitrary input signal, transmitted, for example, by a video amplifier, are:

- 1) that the amplitude characteristic be flat over the frequency range involved ¹⁾,
- 2) that all frequencies present be delayed by the same amount.

The latter condition means that the phase difference between the sinusoidal input and output voltages must be proportional to the frequency; any number of complete phase reversals, may, however, be introduced without affecting the wave-form.

In a communication system with a certain bandwidth (say, 4 Mc/s), it is sufficient in practice to know the amplitude and phase characteristics throughout this band and only a little beyond both limits. For a certain link in such systems, however, a much wider range of measuring frequencies is indispensable. The case we have in mind is that of the feedback amplifier. The amplifier itself and the feedback network together form a closed circuit. If this circuit is interrupted at any point, the ratio of the voltages at the output and input terminals so obtained can be measured and plotted in the complex plane; the result is the Nyquist diagram, which yields information about the stability of the amplifier ²⁾. Now this Nyquist curve has to be extended over a frequency range that on both sides widely exceeds the band for which the amplifier is designed — in fact, from a frequency some 0.1 to 0.05 times the lower limit of the band, up to a frequency some 10 to 20 times the upper limit (*fig. 1*). Measurements at the lower end of this frequency range generally present no difficulties. Often they can even be omitted and the information obtained by calculation, as at rather low frequencies the network constants in most cases are known with sufficient accuracy. At the upper end of the range, however, stray capacitances and transit time effects must be taken into account; this makes calculation too involved and unreliable, if not impossible. Therefore,

²⁾ H. Nyquist, Regeneration theory, Bell Syst. techn. J. **11**, 126-147, 1932.

B. D. H. Tellegen, Philips techn. Rev. **2**, 292, 1947.
H. W. Bode, Network analysis and feedback amplifier design (chapter 8), D. van Nostrand, New York 1945.
F. Strecker, Die elektrische Selbsterregung, Hirzel, Stuttgart 1947.

¹⁾ More strictly speaking: it should have the shape of a Gaussian curve. See, for instance, G. E. Valley and H. Wallman, Vacuum tube amplifiers, Appendix A, Radiation Lab. Series 18, McGraw Hill, New York 1948.

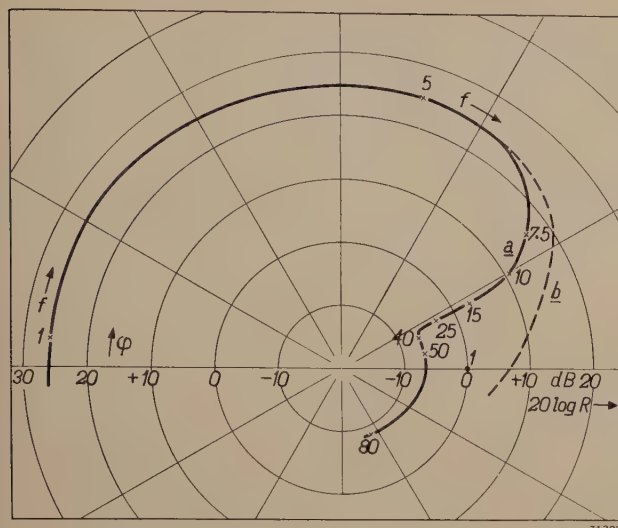


Fig. 1. Complex voltage ratio of two feedback amplifiers, plotted in the complex plane. According to the Nyquist criterion, the amplifier with curve *a*, not comprising the point 1, is stable, and the other, with curve *b*, embracing the point 1, is unstable.

The curves show the locus of the voltage ratio, with the frequency f as a parameter. The amplifiers are intended, for example, to operate over a frequency range of 1-5 Mc/s. In order to obtain the decisive part of the Nyquist curve, measurements have to be carried out at frequencies much higher than the upper limit of this band.

measurements are in this case essential. The instrument to be described was designed for the determination of the Nyquist curve at the higher frequencies. Its frequency range extends from 1 to 100 Mc/s.

General description and theoretical considerations

Choice of the measuring method

An instrument for measuring complex voltage ratios must satisfy certain practical requirements in order to render it suitable for development work. It is highly desirable, for instance, that the change from one measuring frequency to another can be accomplished by means of one knob only, and that the complex ratio can be read directly from dials, either in the form $x + jy$ or as a modulus R and phase angle φ . The accuracy must be better than 0.2 dB in R and 2° in φ . Further, the input terminals of the instrument must be mechanically capable of being introduced into the amplifier circuit at the points at which the voltages are to be compared, in order to avoid long connections between these points and the instrument. This means that the input terminals have to be made in the form of voltage pick-up devices, or probes, attached to the instrument itself by means of flexible cables. The input impedance of these probes must be so high as to form a negligible

load on the circuit at the points with which they are brought into contact.

Various methods for measuring complex voltage ratios have been investigated by Lévy³). The necessary accuracy can best be obtained by a null method, as this requires no voltmeter readings, which are often an important source of errors. A simple and accurate null method, however, is only feasible at a fixed and rather low frequency. This does not necessarily restrict the measuring frequency. By modulating the measuring frequency f_m with an auxiliary frequency f_a , the former may be converted into a fixed intermediate frequency $f_i = f_a - f_m$ below the range of frequencies required for the measurements⁴). The frequency conversion preserves the original complex voltage ratio.

Let $v_1 = V_1 \cos \omega_m t$ denote the input voltage and $v_2 = V_2 \cos(\omega_m t + \varphi)$ the output voltage of the network under test, ω_m being $2\pi f_m$. Then V_2/V_1 is the amplitude ratio and φ the phase difference to be measured.

Let $v_3 = V_3 \cos(\omega_a t + \psi)$ denote an auxiliary voltage of frequency $f_a = \omega_a/2\pi > f_m$; ψ is an arbitrary phase angle. The intermodulation products of v_1 and v_3 include a voltage u_1 :

$$u_1 = V_1 f_{13}(V_3) \cos(\omega_i t - \psi).$$

The corresponding intermodulation product u_2 , due to mixing v_2 and v_3 , is given by the equation:

$$u_2 = V_2 f_{23}(V_3) \cos(\omega_i t + \varphi - \psi).$$

Here $\omega_i = \omega_a - \omega_m$. As is apparent, u_2 and u_1 have the same phase difference φ and — provided the two mixers are similar, i.e. $f_{13}(V_3) = f_{23}(V_3)$ — the same amplitude ratio as the original voltages v_2 and v_1 . The frequency $f_i = \omega_i/2\pi$ of u_1 and u_2 , however, can be made much lower than f_m .

Due to this preservation of the complex voltage ratio, a measurement at a fixed and intermediate frequency can be substituted for the measurement at a variable and very high frequency f_m , compensation being obtained at a fixed, much lower frequency f_i . This, in fact, is the principle adopted in the instrument to be described.

The frequency-conversion system requires two generators, one supplying the variable measuring frequency f_m , the other the auxiliary frequency f_a differing from f_m by a fixed amount f_i . Finding a practical solution for the construction of these generators, with the necessary high constancy in frequency difference f_i , was one of the main problems. Another was the avoidance of stray effects that would falsify the measurements; questions relating to this problem are treated in an Appendix.

³) M. Lévy, Methods and apparatus for measuring phase distortion, *Electr. Communication* **18**, 206-228, 1940.

⁴) E. Peterson, J. G. Kreer and L. A. Ware, *Bell Syst. techn. J.* **13**, 680-700, 1934.

In the third place we mention the design of a novel phase shifting device used for balancing the intermediate-frequency voltages.

The instrument can be divided logically into a high-frequency circuit comprising the generators, the mixers etc., and an intermediate-frequency (and associated low-frequency) circuit consisting of the balancing and indicating devices.

They are kept constant in frequency by crystal oscillators Q_1 and Q_2 , generating the frequencies 200.3/27 and 200.0/27 Mc/s, respectively. Both these frequencies are multiplied 27 times by three successive triplers (see blocks Mu_1 , Mu_2). Another oscillator, O_v , has a frequency f_v , variable from 201.3 to 300.3 Mc/s. Fractions of the voltage generated by O_v are applied to the oscillators O_1 and O_2 , which at the same time function as mixers.

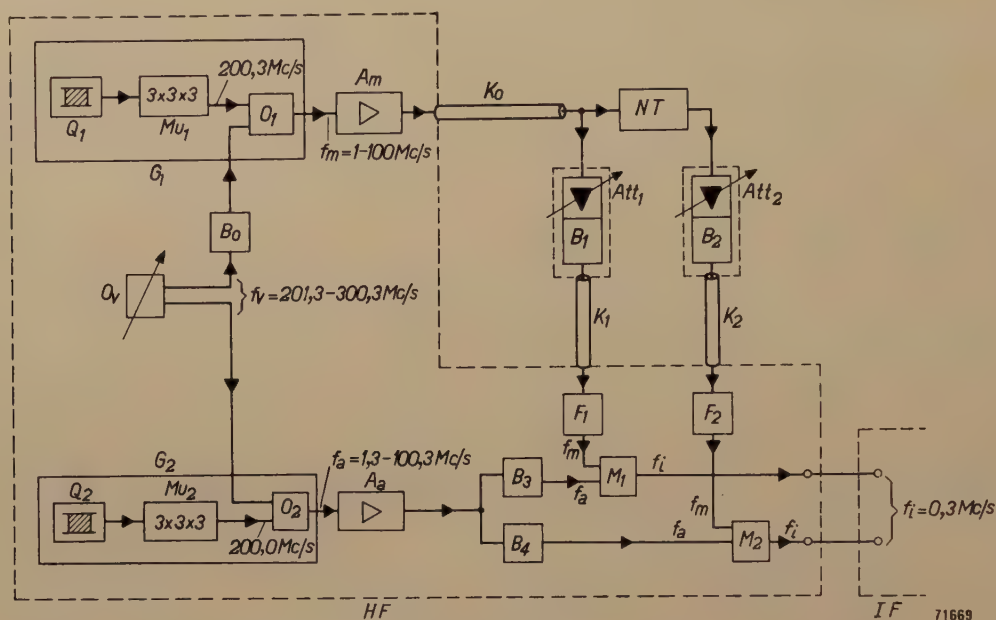


Fig. 2. Block diagram of the H.F. circuit. G_1 generator comprising a crystal oscillator Q_1 and a frequency multiplier Mu_1 , synchronizing an oscillator O_1 at the frequency 200.3 Mc/s. G_2 generator similar to G_1 but with a frequency 200.0 Mc/s. O_v oscillator with a frequency f_v variable from 201.3 to 300.3 Mc/s. The measuring frequency $f_m = f_v - 200.3$ Mc/s. = 1 to 100 Mc/s is obtained from O_1 , working as a mixer. An auxiliary frequency $f_a = f_v - 200.0$ Mc/s is similarly obtained from O_2 . $f_i = f_a - f_m =$ intermediate frequency = 0.3 Mc/s. A_m , A_a wide-band amplifiers. K_0 , K_1 , K_2 coaxial cables. NT network under test. Att_1 , Att_2 variable attenuators. B_0 , B_1 , B_2 , B_3 , B_4 buffers. F_1 , F_2 band-stop filters. M_1 , M_2 mixing circuits.

$H.F.$ denotes the H.F. chassis, $I.F.$ the I.F. chassis.

The high-frequency circuit

The production of two frequencies differing by an approximately constant amount can be accomplished by mechanically ganging the tuning capacitors of two valve oscillators; a similar technique is adopted in normal superheterodyne receiving sets, in which the tuning circuits of the H.F. amplifier and the local oscillator are ganged together. In our case, however, where $f_i = 300$ kc/s and the maximum tolerable deviation is only 0.5 kc/s, mechanical ganging would not provide the necessary constancy in frequency difference.

The solution adopted is shown in principle in fig. 2. The generators G_1 and G_2 provide the fixed frequencies 200.3 and 200.0 Mc/s, respectively.

One of the intermodulation products of O_1 has the frequency $(f_v - 200.3)$ Mc/s, which is used as the measuring frequency f_m . Since f_v is variable from 201.3 to 300.3 Mc/s, f_m has a range from 1 to 100 Mc/s. In the same way the auxiliary frequency $f_a = (f_v - 200.0)$ Mc/s is obtained from O_2 . The frequency f_a differs from f_m by the fixed amount of 0.3 Mc/s, i.e. by the intermediate frequency f_i .

The output voltages of G_1 and G_2 are amplified in the wide-band amplifiers A_m and A_a , respectively. A cable conveys the output of A_m to the network under test. The input and output voltages of this network are applied, via attenuators (Att_1 , Att_2), to mixing circuits (M_1 , M_2), where they are mixed with voltages derived from the amplifier A_a .

Interposed buffer stages (B_1, B_2, B_3, B_4) prevent unwanted couplings (see Appendix). The mixers produce intermediate-frequency output voltages, which are compared in the intermediate-frequency circuit to be described in the next paragraph.

The intermediate-frequency circuit

As shown above, the high-frequency circuit delivers two 0.3 Mc/s output voltages having the same complex ratio as the high-frequency voltages present at the input and output terminals, respectively, of the network under test. In the intermediate-frequency circuit, these 0.3 Mc/s voltages are made to cancel each other by changing the amplitude and phase of one of them until the sum of the two voltages becomes zero. The balance indication is obtained in the following way. The voltages to be compared are applied to the input terminals of an amplifier (A_{IF} , fig. 3). With the aid of a beat oscillator the out-of-balance voltage is converted into a low-frequency voltage, which is made audible by means of an audio-frequency amplifier and a loudspeaker. The vanishing of the beat note indicates balance. The amplitude and phase adjustments necessary for the above operations are accomplished by means of a variable attenuator Att_3 and a variable phase shifter Φ (fig. 3).

From the dials of these instruments the ratio can be read directly as an amplitude change in dB and a phase shift ⁵⁾.

Audible indication is to be preferred to visual, as it has the considerable advantages that beat notes due to unwanted intermodulation products are easily distinguishable from the normal one, and that the influence of the noise level is smaller.

On the input side of the IF circuit, similar filters (F_3 and F_4) pass the intermediate frequency

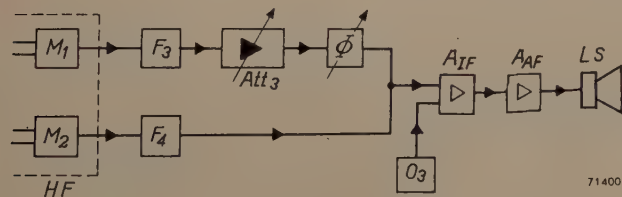


Fig. 3. Block diagram of the I.F. chassis. F_3, F_4 low-pass filters. Att_3 variable attenuator. Φ phase shifter. A_{IF} I.F. amplifier. O_3 beat oscillator. A_{AF} A.F. amplifier. LS loudspeaker. M_1, M_2 , mixing circuits (see fig. 2).

Att_3 and Φ are so adjusted that the beat note from the loudspeaker vanishes, indicating that the two I.F. voltages applied to A_{IF} balance.

⁵⁾ Attenuators Att_1 and Att_2 were here supposed to have equal attenuations. If they have different settings — as in general will be the case — the difference in readings of Att_1 and Att_2 must be added to the reading of Att_3 .

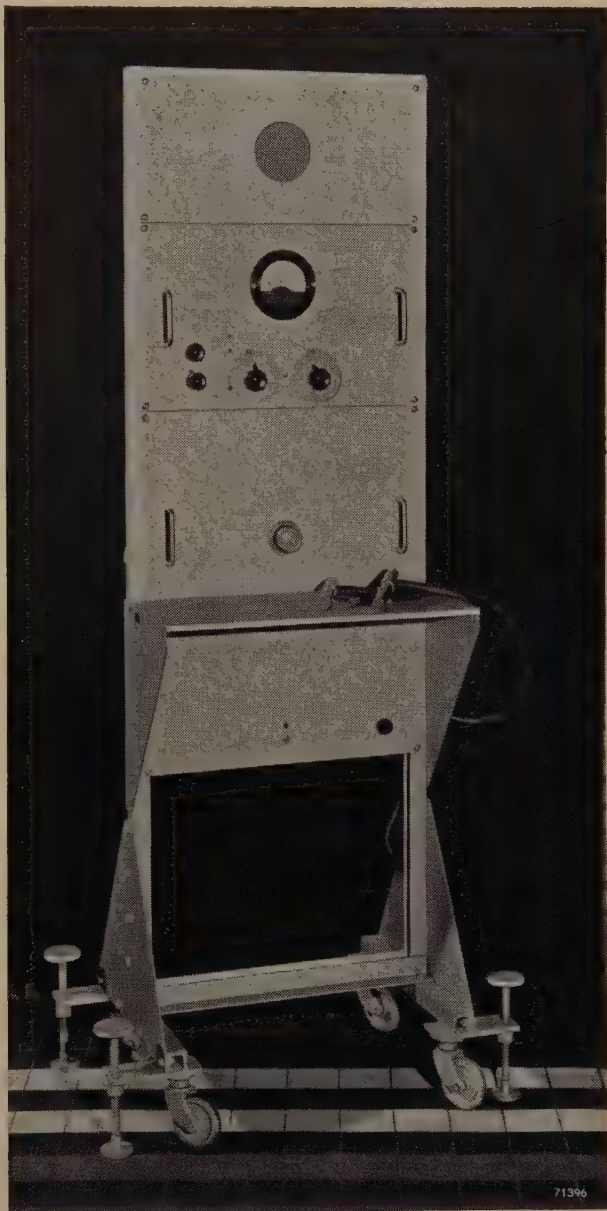


Fig. 4. View of the complete instrument. From top to bottom: loudspeaker panel, I.F. panel, H.F. panel, table (with the two probes) and supply panel.

f_i and stop the high frequencies f_m and f_a that are always present to some extent at the output terminals of the mixers.

The amplifier A_{IF} is selective. It need not satisfy special requirements in respect of phase or amplitude, since its only function is to amplify the out-of-balance voltage.

The attenuator Att_3 must not introduce any change of phase shift over the entire attenuation range (the same applies, by the way, to the attenuators Att_1 and Att_2 of the H.F. circuits, fig. 2); the phase shifter must similarly have an attenuation that is independent of the setting. Details of these components will be discussed in later paragraphs.

To conclude this general description we give in *fig. 4* a photograph of the complete instrument. A slightly different version, developed at Philips Telecommunication Industries, Hilversum, Netherlands, is described elsewhere ⁶⁾.

Constructional details of the H.F. circuit

The high-frequency chassis is shown in *fig. 5a* and *b*. Various components will be discussed below.

Crystal oscillators and frequency multipliers

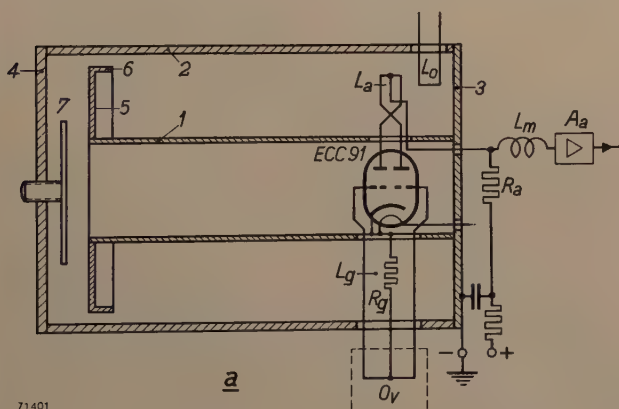
The crystal oscillators O_1 and O_2 (*fig. 2*) operate at frequencies of 200.3/27 and 200.0/27 Mc/s, respectively. These frequencies must differ by a fixed amount in spite of temperature fluctuations, by which they are slightly affected. In order to keep this difference as constant as possible, the two quartz crystals have been placed in a common brass block, so that they are subjected to the same variations of temperature. In this way f_i is kept within 299.5 and 300.5 kc/s.

The frequency multipliers, of quite normal design, each consist of three tripler stages. The output valve of each multiplier is inductively coupled with the resonator of its respective oscillator, thereby keeping the latter synchronized.

Combined oscillator-mixers O_1 , O_2

The oscillators O_1 , O_2 and O_v are all of the same type except that O_v is not synchronized. The resonator (*fig. 6a*), of the so-called foreshortened coaxial type, has a concentrated capacitance between the outer wall 2 and the flange 6 forming an extension of the inner wall 1. Further details are explained in the subscript of the figure.

⁶⁾ G. Thirup and F. A. Vitha, to appear shortly in Communication News.



In the oscillators O_1 and O_2 , the oscillator valves operate at the same time as mixers. At the inputs, both the self-generated voltage and the voltage from the multiplier are fed in push-pull; on the output side, however, the valves are connected in parallel ⁷⁾. This is shown in *fig. 6a*, but more clearly in *fig. 6b*, where the cavity resonator has been replaced by a circuit with lumped L - C elements. If the system is completely symmetrical, in this way only the frequencies $mf_v \pm n \times 200.3$ or $mf_v \pm n \times 200.0$ Mc/s occur in the output of O_1 and O_2 , respectively, where m and n are confined to odd integers. In an asymmetrical circuit, on the contrary, m and n can also assume even values. So by aiming at symmetry, we get rid of many undesirable modulation products. For further details the reader is referred to the Appendix.

200-300 Mc/s buffer stage (B_0)

As shown in *fig. 2*, a buffer stage B_0 has been inserted between the oscillators O_1 and O_v . Its object is to prevent a signal from O_1 reaching O_2 . If, for example, the frequency 200.3 Mc/s could reach O_2 , it would mix with 200.0 Mc/s at that point and produce a spurious intermediate-frequency signal that would interfere with the measurement. In the opposite direction, from O_v to O_1 , the buffer must readily transmit the frequency f_v , ranging from 201.3 to 200.3 Mc/s.

The buffer B_0 consists of two type EC 80 triodes ⁸⁾ in cascade, with grounded grids. The ratio between the transfer

⁷⁾ This is a modification of a mixing system described by A. van Weel, Philips techn. Rev. 8, 193-198, 1946, in particularly *fig. 2*.

⁸⁾ K. Rodenhuis, Two triodes for reception of decimetric waves, Philips techn. Rev. 11, 79-89, 1949.

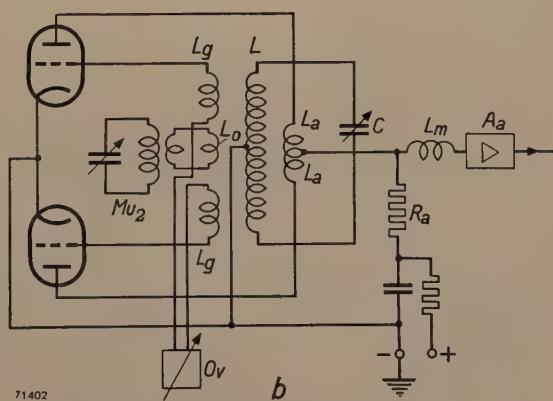


Fig. 6. a) Sectional view of oscillator O_2 (*fig. 2*). Cylinders 1 and 2, bottom 3 and lid 4 form a coaxial cavity resonator. 1 ends in a disc 5 with a rim 6 forming a capacitor with the outer cylinder 2. The movable disc, 7, is provided as a trimmer.

L_g grid circuits, L_a anode circuits of a double triode ECC 91 in push-pull arrangement, coupled with the field in the resonator. L_0 loop fed by the frequency multiplier (Mu_2 , *fig. 2*), which keeps the frequency at the right value (200.0 Mc/s). The loops L_g have been extended outside the resonator and are coupled with the field of the oscillator O_v with frequency f_v .

The output (frequency $f_a = f_v - 200.0$ Mc/s) is taken from the common anode resistor R_a and supplied, via an inductance L_m (which counteracts the effect of stray capacitances), to the amplifier A_a .

b) shows what the diagram (a) would be if an L - C circuit could be used instead of the resonator.

admittance from cathode to anode to that in the opposite direction is, per stage, approximately $1/\mu$, μ being the amplification factor of the valve. The value of μ for an EC 80 triode is 80. The two valves in cascade yield a ratio of 6400 (76 dB), which has appeared quite sufficient.

The buffer stage can be seen in the middle of figs. 5a and b.

Wide-band amplifiers

The bandwidth to be covered by the amplifiers A_m and A_a (fig. 2) is considerable; it amounts to 100 Mc/s. Fortunately, the requirements with regard to the amplitude and phase characteristics within this band are not stringent, a deviation of ± 3 dB from the flat (low-frequency) part of the characteristic being tolerated, and the phase shift being of no importance at all.

For a conventional one-stage amplifier, with a resistance R in the anode circuit and a stray capacitance C in parallel with R , the frequency at which the gain-frequency characteristic has dropped 3 dB below the flat part is $1/(2\pi RC)$. This frequency limit can be raised by inserting a suitable inductance in the lead from the anode of the valve to the grid of the next valve⁹). This simple measure is made use of at several points of the circuits (for instance, L_m in fig. 6), but in the case of the amplifier it would not yield a bandwidth as wide as required in our case. To meet the demand we have made use of a more complicated circuit, due to Boghosian¹⁰). It is shown in fig. 7. With a

pentode EF 42 (mutual conductance 9 mA/V) and $R = 200 \Omega$, the gain per stage is 1.8, and if the relations between the various circuit parameters mentioned in the subscript of fig. 7 are satisfied, the amplitude characteristic is flat to within a few percent at frequencies up to 100 Mc/s. So five stages in cascade can be used without an excessive reduction of gain at the higher frequencies.

Various circumstances complicate the operation of the circuit. The coil L_2 , for instance, has a self-capacitance, which at very high frequencies makes the reactance higher than that of the pure inductance. This difficulty can be overcome by screening the coil, so that most of the self-capacitance appears in parallel with the capacitances C_a and C_g (see fig. 7). Furthermore, the impedance of the by-pass capacitor C_3 must be low at all frequencies from 1 to 100 Mc/s. A specially wound capacitor, with paper dielectric, was designed for the purpose, in order to avoid resonances in its windings and to keep the inductance low. The capacitor is housed in a brass can, which forms the earthed side and is soldered into a hole in the chassis as near as possible to the screen-grid contact of the valve socket. In this way the inductance of the by-pass connection between this contact and the chassis, via the capacitor, is kept as low as — or even lower than — the inductance of the leads inside the valve. In fig. 5 several of these capacitors are visible.

The amplifier A_m has four stages of the type mentioned and produces an output voltage of maximum 0.1 V across 70 Ω ; A_a , with five stages and a higher input, supplies about 1.5 V to the buffers B_3 and B_4 . In both amplifiers, a circuit tuned to the intermediate frequency f_i has been inserted in one of the cathode leads. Thus heavy negative feedback exists for f_i , resulting in a low gain of unwanted I.F. voltages (see Appendix).

Attenuators Att_1 , Att_2 and buffers B_1 , B_2

The mixing circuits M_1 and M_2 require input voltages whose levels do not differ too widely. The input and output voltages of the network under test, however, may differ from one another quite considerably in either sense. If, for instance, the network is an amplifier and f_m is within its working frequency range, the output voltage may be some 30 or 40 dB higher than the input voltage. If, on the other hand, f_m is far beyond the working frequency band, the network will in general have a loss of, say, 10 dB. To make up for these differences, a variable attenuator must be introduced between each side of the network under test and the corresponding mixer. These attenuators are variable in five steps of 10 dB each.

The phase shift that these attenuators inevitably introduce should be independent of the attenuator

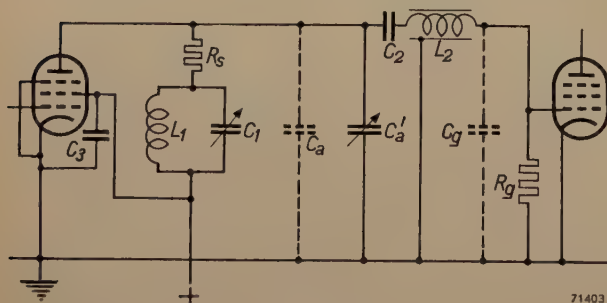


Fig. 7. Circuit diagram (due to Boghosian¹⁰)) of one stage of the wide-band amplifiers A_m and A_a (fig. 2). C_a is the anode and wiring capacitance, C_a' the capacitance of a trimmer, C_g the input capacitance and R_g the input resistance of the next valve, C_3 a by-pass capacitor.

For correct functioning, the following relations have to be satisfied:

$$C_a + C_a' = \frac{1.6}{2\pi f_0 R_s}, \quad C_g = \frac{2.0}{2\pi f_0 R_s}, \quad C_1 = \frac{1.067}{2\pi f_0 R_s},$$

$$L_1 = \frac{2R_s}{2\pi f_0}, \quad L_2 = \frac{0.6R_s}{2\pi f_0}.$$

Here f_0 is a frequency 10% higher than the bandwidth.

⁹) See, for instance, H. J. Lindenhovius, G. Arbelet and J. C. van der Breggen, Philips techn. Rev. 11, 206-214, 1950.

¹⁰) Described in chapter 17 of H. W. Bode's book mentioned in footnote 1).

setting. This can best be accomplished with attenuators of the capacitive type, essentially consisting of a potentiometer formed by two capacitors in series (C_4 and $C_5 + C_6$, fig. 8). The attenuation desired can be set up by varying one of the capacitances. In the present case, where a high input impedance is desired, the system with a (small) variable series capacitance is to be preferred.

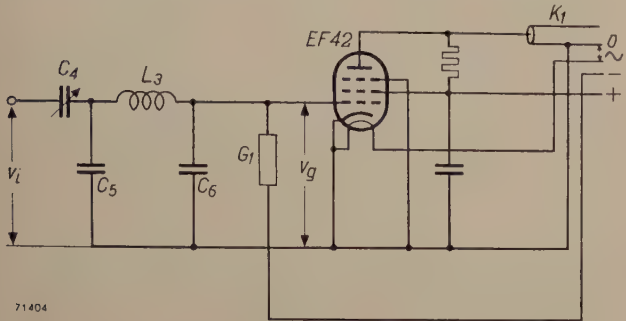


Fig. 8. Diagram of the attenuator Att_1 and the buffer B_1 . C_4 variable capacitor of the sliding type. C_5 wiring capacitance. L_3 wiring inductance. G_1 input conductance (including grid leak) of the buffer valve C_6 input capacitance of this valve. K_1 cable (140 Ω).

In fig. 8, C_4 is the variable series capacitor of the attenuator, C_5 the fixed capacitance of the wiring, C_6 the fixed input capacitance of the subsequent valve (buffer valve), L_3 the inductance of the wiring and of the leads inside the valve, and G_1 the grid leak conductance (including the input conductance of the valve).

At the lower end of the measuring frequency range (f_m near 1 Mc/s), the influence of L_3 — estimated as 0.05 μ H — may be neglected. For the ratio between the voltage v_g at the grid of the buffer valve and the input voltage v_i we then find:

$$\frac{v_g}{v_i} = \frac{j\omega_m C_4}{G_1 + j\omega_m (C_4 + C_5 + C_6)}, \quad \dots \quad (1)$$

where $\omega_m = 2\pi f_m$. At these lower frequencies, G_1 may be put equal to the conductance of the grid leak = $10^{-6} \Omega^{-1}$. With $f_m = 1$ Mc/s, $C_5 = 2.5$ pF and $C_6 = 15$ pF, we find from (1) that a variation of C_4 from 2.5 pF downwards to zero causes a variation in phase shift of less than 0.1° — an amount small enough to be of no consequence.

At the upper end of the f_m range the influence of L_3 can no longer be neglected. We then find a more complicated formula. Moreover, G_1 is now dependent on frequency (mainly due to inductance in the cathode lead and to transit time effects). At $f_m = 100$ Mc/s, G_1 is estimated as $10^{-3} \Omega^{-1}$. The phase shift produced by again varying C_4 from 2.5 pF down to zero is then found to be slightly less than 1° , which is still acceptable.

For a capacitor with a maximum capacitance of 2.5 pF and a minimum capacitance low enough to provide the necessary attenuation of 50 dB, the sliding type is to be preferred to the rotary type. It has been given the form of a probe ¹¹⁾ (fig. 9). The variable capacitor, together with the buffer valve, is housed in an earthed metal tube. One electrode, in the shape of a rod, is fixed and is connected to a protruding pin; the latter makes contact with the input or output terminal of the network under test. The other is cylindrical and can be moved coaxially with respect to the fixed electrode. As explained elsewhere ⁹⁾, the attenuation varies almost logarithmically with the distance, provided this distance is large compared with the internal diameter of the tube.

The moving electrode can be located by a detent at five calibrated settings, covering a range of 10-50 dB; the detent consists of a steel ball pressed by a

¹¹⁾ A capacitive attenuator of a similar type, intended for changing the range of a H.F. valve voltmeter, was described at the end of the article mentioned in footnote ⁹⁾.

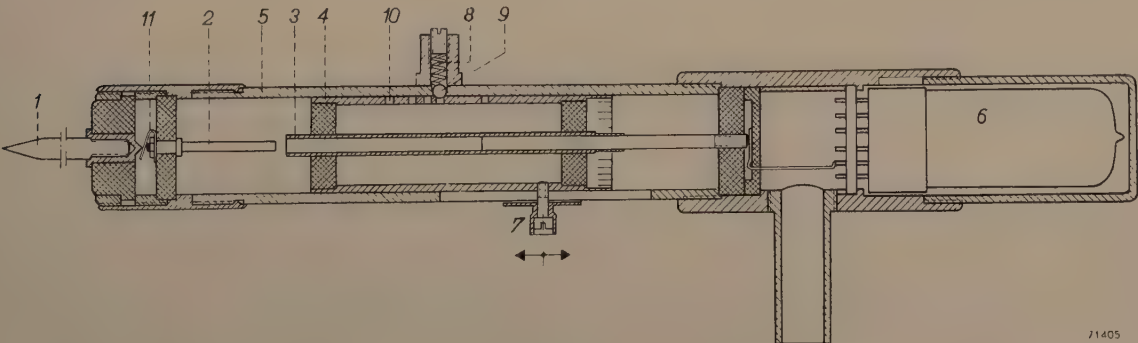


Fig. 9. Sectional view of the probe containing an attenuator and a buffer according to fig. 8. 1 contact pin. 2 fixed electrode. 3 tubular electrode mounted in a sliding part 4. 5 earthed metal tube. 6 buffer valve EF 42. 7 knob for moving 4. 8 spring pressing a steel ball 9 into one of the holes 10 to locate the sliding assembly in one of the five calibrated positions. A leaf spring 11 establishes a flexible contact between 1 and 2 to protect the calibration of the attenuator from disturbance by accidental damage to the pin 1.

spring into a series of holes drilled in the moving electrode assembly.

The input capacitance is only 4.5 pF at low and 2.0 pF at high attenuations.

The sliding electrode is connected to the control grid of the buffer valve, a type EF 42 pentode. This valve feeds into a cable, which connects the probe to the instrument itself and which also contains the leads for the heater current and the D.C. supply. The characteristic impedance of the cable is 140 Ω .

Further details may be gathered from fig. 9.

Buffer stages B_3 , B_4 and mixing circuits M_1 , M_2

The buffer B_4 and the mixer M_2 (fig. 2) together form a unit, the diagram of which is shown in fig. 10. In each circuit a type EF 42 pentode is used. A parallel circuit L_4 - C_7 , tuned to f_i , is connected in series with the probe cable. Its

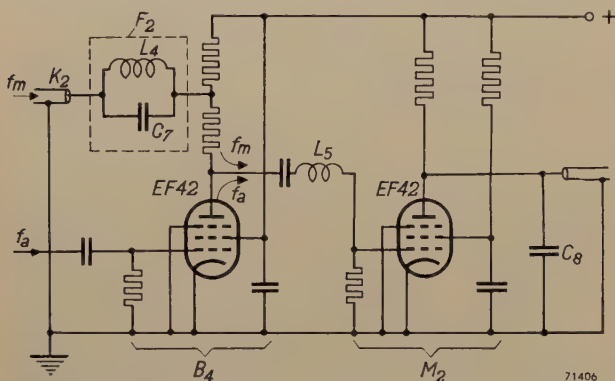


Fig. 10. Diagram of buffer B_4 and mixer M_2 . K_2 cable arriving from one of the probes. L_4 - C_7 filter (F_2 in fig. 2) suppressing f_i . L_5 inductance for counteracting stray capacitance effects. C_8 input capacitor of low-pass filter F_4 (fig. 3).

function is to suppress the intermediate frequency (see Appendix). An inductance L_5 has been inserted in the lead from the anode of the buffer valve to the control grid of the mixing valve to counteract the adverse effect of stray capacitances⁹⁾.

Stages B_3 and M_1 are similar to B_4 and M_2 .

Constructional details of the I.F. circuit

Attenuator Att_3

By means of the attenuator Att_3 (fig. 3) the two intermediate-frequency voltages to be compared

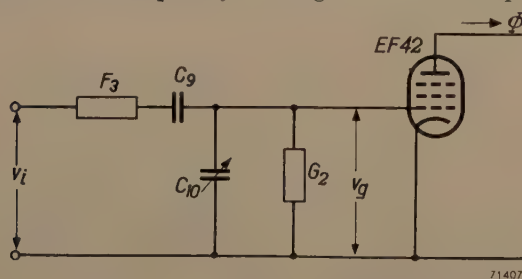


Fig. 11. Attenuator Att_3 (fig. 3) consisting in essence of a fixed capacitor C_9 and a variable capacitor C_{10} . F_3 low-pass filter. G_2 input conductance of a pentode EF 42 feeding the bridge circuit of the phase shifter Φ (see fig. 13a).

can be made equal in amplitude without appreciably changing the phase difference. The attenuator consists of the air capacitor C_{10} in combination with the other components shown in fig. 11. In contrast to the attenuators Att_1 and Att_2 (fig. 8), the parallel capacitor C_{10} is variable and the series capacitor C_9 is fixed.

The reason for this choice is the following. The desired maximum attenuation of 20 dB can be obtained either with a parallel capacitor of 500 pF maximum or with a series capacitor in the order of 10 pF. The former is of a standard type with rotary plates, and in the latter case the low capacitance would necessitate a sliding movement — as shown in fig. 9 —, in order to provide sufficient separation of the electrodes. For panel mounting the rotary type is much to be preferred.

In this circuit the frequency is constant (0.3 Mc/s). The filter F_3 (fig. 11) can be represented by a resistance of 900 Ω and the conductance of the grid leak is $10^{-6} \Omega^{-1}$. By a proper choice of C_9 and of the extreme values of C_{10} (40-500 pF), the attenuation can be varied over a range of 20 dB (to be read from the dial of C_{10}), without introducing an error in phase shift of more than 0.5° .

Phase shifter

The principle of the phase-shifting device (Φ in fig. 3) is shown in fig. 12. Two similar loops, l_1 and l_2 , are placed perpendicular to each other inside a metal tube. It can be shown by waveguide theory

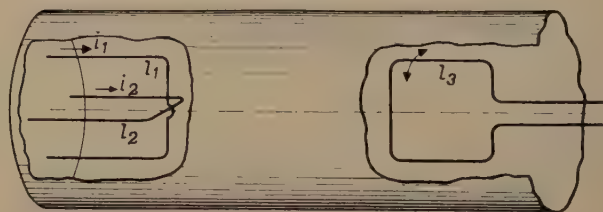


Fig. 12. Phase shifter. Alternating currents i_1 and i_2 of equal amplitudes and in quadrature flow through two similar loops l_1 and l_2 placed perpendicular to each other inside a metal tube. At some distance, a rotating magnetic field of circular symmetry is produced, which acts upon a rotatable loop l_3 , placed therein. When l_3 is turned about its axis, the voltage induced in the loop remains constant in amplitude, but is shifted in phase by an amount equal to the angle of rotation, which is readable on a dial.

that if the loops carry alternating currents of equal strengths but in quadrature, then beyond a certain distance from the loops there is a rotating magnetic field with circular symmetry. In this field a third loop, l_3 , is placed. In it a voltage is induced, proportional in amplitude to the currents in l_1 and l_2 . If l_3 is rotated about the axis of the tube, the induced voltage remains constant in amplitude but varies in phase by an amount equal to the angle over which the loop has been turned.

As we shall see presently, the currents for l_1 and l_2 are supplied by the valve shown in fig. 11. In this way the voltage derived from the input of the network under test can be balanced against that derived from the output of the network. The latter voltage appears at the output of filter F_4 (fig. 3).

It only remains to be explained how the currents for the loops l_1 and l_2 are obtained from the valve EF 42 in fig. 11. The valve feeds a bridge circuit C_{11} - R_1 - C_{12} - R_2 (fig. 13a), from which are taken

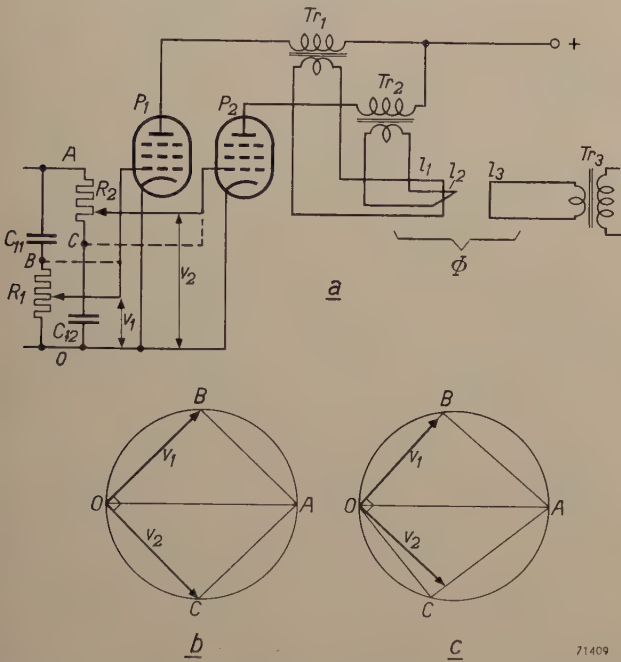


Fig. 13. a) Circuit providing the loop currents for the phase shifter Φ . R_1 - C_{11} - R_2 - C_{12} bridge fed by the pentode shown in fig. 11. P_1 , P_2 two other pentodes EF 42. Tr_1 , Tr_2 current transformers. Tr_3 step-up transformer. The transformers Tr_1 , Tr_2 and Tr_3 have Ferroxcube cores. b) If $R_1 = R_2 = 1/(\omega_i C_{11}) = 1/(\omega_i C_{12})$, the vectors representing the voltages across the bridge arms form a square $OBAC$. The voltages OB and OC can then be used as grid voltages, as shown in (a) by dotted lines. c) In order to allow for trimming, the circuit parameters are so chosen that the angle BOC is slightly greater than 90° , and the grid voltages v_1 and v_2 are taken from sliding contacts on R_1 and R_2 . These contacts can be so adjusted that v_1 and v_2 are equal in amplitude and at right angles to each other.

the grid voltages for a pair of pentodes P_1 and P_2 . Transformers in the anode circuits of P_1 and P_2 match the high impedances of the valves to the low impedance of the loops (each loop consists of one single turn only, to avoid the excitation of undesirable modes in the waveguide).

If the resistances R_1 and R_2 and the capacitances C_{11} and C_{12} of the bridge circuit are such that $R_1 = R_2 = 1/(\omega_i C_{11}) = 1/(\omega_i C_{12})$, then the vectors representing the voltages across the bridge arms form a square ($OBAC$, fig. 13b). The voltages OB and OC are thus in quadrature and equal in amplitude. Used as grid voltages for the valves P_1 and

P_2 , they produce in the anode circuits alternating currents that are also in quadrature and — provided the transconductances of the valves are the same — of equal amplitude. The currents supplied by the transformers Tr_1 and Tr_2 , therefore, can be fed to the loops l_1 and l_2 of the phase shifter. As, however, the bridge elements and the intermediate frequency may deviate slightly from the required values, and the transformers and the valves may differ in their respective characteristics, means are necessary to correct for these deviations. Therefore, the grid voltages are not taken from the points B and C (fig. 13a), but from sliding contacts on the resistors R_1 and R_2 . The values of the bridge elements are so chosen that the angle BOC (fig. 13c) is somewhat greater than 90° . By moving the contact on R_1 , the grid voltage of valve P_1 is varied in amplitude but not in phase, and by moving the contact on R_2 the grid voltage of P_2 is varied in phase without an appreciable change of amplitude.

The circuit can be adjusted in the following way. A voltmeter is connected across the secondary winding of a transformer Tr_3 which steps up the voltage induced in the loop l_3 . A reading of this meter is taken with l_3 turned into the position where it is parallel with l_2 . Next, l_3 is turned parallel with l_1 , and the sliding contact on R_1 adjusted until the same reading of the voltmeter is obtained. If now l_3 is rotated over 360° , the voltage will in general not remain constant during the rotation, due to the loop currents not being exactly in quadrature. In fact, if the voltmeter reading is plotted in polar co-ordinates as a function of the angle of rotation, an ellipse is obtained. The phase difference is now adjusted by means of the sliding contact on R_2 until the ellipse becomes a circle.

With this adjustment, even a slight content of second harmonic may be very troublesome. For this reason, a milliammeter in series with the diode detector in the amplifier A_{IF} can be used with advantage instead of the voltmeter across Tr_3 .

Other components

The voltage induced in l_3 and stepped up by transformer Tr_3 is applied to the control grid of a type EF 42 pentode. The voltage from the filter F_4 (fig. 3) is applied to the control grid of another EF 42 pentode. Since the anodes of these valves are connected in parallel, in the common anode lead an alternating current is obtained which vanishes if the grid voltages are equal in amplitude and opposite in phase, i.e. if the two intermediate-frequency voltages to be compared are made to balance.

The rest of the intermediate-frequency circuit and the audio-frequency circuit (fig. 3) are very similar to the corresponding parts of a normal broadcast receiver, so they need no further description.

Corrections

A condition — so far mentioned only in passing — which has to be fulfilled is that the channels Att_1 - B_1 - K_1 - F_1 - M_1 and Att_2 - B_2 - K_2 - F_2 - M_2 (fig. 2) must be equal in transmission properties. The

same applies to the channels B_3-M_1 and B_4-M_2 (fig. 2) and to the channels $M_1-F_3-Att_3-\Phi-A_{IF}$ and $M_2-F_4-A_{IF}$ (fig. 3). For this reason, corresponding components in each of these pairs of channels have been given identical electrical properties as far as possible. Valves, for instance, have been selected for equality in slope, and for F_3 and F_4 low-pass filters (cut-off frequency 0.35 Mc/s) have been preferred to band-pass filters, as the transmission properties of the former are less dependent on temperature and on possible variations of the intermediate frequency.

In spite of all care, however, some asymmetry remains, as can be found by connecting Att_2 to the same point as Att_1 and otherwise using the instrument in the normal way: then, as a rule, the intermediate-frequency voltages do not balance, as they should in case of exact symmetry. These residual amplitude and phase distortions have been measured and plotted as functions of frequency. The curves so obtained show the corrections which have to be applied to the dial readings, if the utmost precision is needed. The corrections never exceed 3% in the amplitude ratio and 3° in the phase angle. The amplitude correction varies somewhat with time owing to ageing of the valves, but by readjusting a trimmer potentiometer the original correction curve can be obtained again without any difficulty. The correction for phase difference is practically constant with time.

Appendix: Suppression of stray effects

The instrument described can only be expected to function well if the utmost care is taken to avoid stray effects that would falsify the measurements. These stray effects are partly due to the presence of unwanted couplings between the input and output of the network under test, partly also to unwanted frequencies arising at certain points of the circuit. As will appear from the survey given below, the remedies consist in screening and in the insertion of various buffers and filters.

Necessity of buffers B_1, B_2, B_3 and B_4

In the absence of the buffers B_1, B_2, B_3 and B_4 (fig. 2), a coupling by way of Att_1, F_1, F_2 and Att_2 would exist between the input and output of the network under test. Therefore, the measurements would not be performed on the original network but on this network plus the extra coupling. As a means of suppressing this coupling in the direction from input to output, the buffers B_3 and B_2 have been inserted; they are networks transmitting readily

in the direction of the arrows but presenting a high attenuation the other way. Similar buffers, B_4 and B_1 , prevent a coupling from output to input.

A further purpose of the buffers B_1 and B_2 is to prevent a signal with the auxiliary frequency f_a , which is present at the input terminals of the mixers M_1 and M_2 , from reaching the network under test. Here, owing to its large amplitude (see below), this signal would make the valves operate over a non-linear part of their characteristics and so give rise to unwanted modulation products.

Necessity of buffer B_0 and of screening between the generators

If a signal with the frequency 200.0 Mc/s, present in the generator G_2 , (fig. 2), were to reach the oscillator-mixer O_1 , then, by mixing with signals of frequencies 200.3 Mc/s and f_v , it would cause the formation of various unwanted frequencies. Similarly, a signal with the frequency 200.3 Mc/s reaching O_2 from G_1 would be the cause of unwanted frequencies being produced in O_2 . In the table below, the wanted frequencies and some unwanted ones are mentioned. All these modulation products are amplified by the amplifiers A_m and A_a . The 0.3 Mc/s component passes directly on to the I.F. circuit and causes a wrong measuring result. Moreover, in the mixers M_1 and M_2 the unwanted components with the frequencies f_m and f_a are added to the wanted components, which also disturbs the measurement.

Table, showing some of the frequencies produced in the oscillators-mixers O_1 and O_2 , the unwanted ones by interaction between O_1 and O_2 .

	Output frequencies from O_1 Mc/s	Output frequencies from O_2 Mc/s
Wanted	$f_v - 200.3 = f_m$	$f_v - 200.0 = f_a$
Unwanted "first order" modulation products	$200.3 - 200.0 = f_i$	$200.3 - 200.0 = f_i$
Unwanted "higher order" modulation products of importance	$f_v - 200.0 = f_a$	$f_v - 200.3 = f_m$

The formation of unwanted output components in O_1 and O_2 can be suppressed at the root of the evil by careful screening, combined with the insertion of a buffer (B_0) between O_1 and O_2 , and further by the insertion of 0.3 Mc/s band-stop filters in the amplifiers A_m and A_a .

the presence of f_m at O_2 . As these frequencies lie very close together, the response of the amplifiers, buffers and filters to a signal of frequency f_a will be substantially the same as that to a signal of frequency f_m .

Returning now to point b in fig. 14, we have a signal of frequency f_a arriving legally by way of A_a and B_4 , and an unwanted signal of the same frequency arriving via A_m , NT , B_2 and F_2 . The phase difference between these signals can have any value and will depend on f_a and on the properties of the network under test. In order to keep the resulting f_a signal at b sufficiently constant in phase under all circumstances, the level of the parasitic f_a component must be at least 50 dB below the level of the legal f_a component, i.e. 10 dB below the level of the legal f_m component (see fig. 14). The same holds for points c , d and e . This requirement is not difficult to meet.

For a similar reason, at b the parasitic f_m signal must be 50 dB below the legal f_m signal, i.e. 90 dB below the f_a signal, and this holds also for points f and g . This difference of 90 dB is a rather severe requirement. It is mainly met by blocking the way from O_1 to O_2 via O_v (attenuation of 76 dB by buffer B_0).

Higher-order modulation products of minor importance

Neglecting the presence of parasitic signals at the input terminals of O_1 and O_2 , we can write the frequencies at the output terminals as

$$mf_v \pm n \times 200.3 \text{ Mc/s} \quad (2)$$

and

$$pf_v \pm q \times 200.0 \text{ Mc/s}, \quad (3)$$

respectively. In the general case the coefficients m , n , p , and q are 0, 1, 2, 3,... Frequencies corresponding to the $+$ signs in (2) and (3) can be left out of consideration, as they are well above the frequency range of the amplifiers A_m and A_a .

Mixing of the series (2) and (3) in M_1 and M_2 produces at the output terminals of the HF circuit a new series of frequencies:

$$s(pf_v - q \times 200.0) \pm r(mf_v - n \times 200.3) \text{ Mc/s}, \quad (4)$$

where the coefficients r and s are 0, 1, 2, 3,... In the special case of $m = n = p = q = r = s = 1$, and with the minus sign before r , we find the wanted intermediate frequency

$f_i = 0.3 \text{ Mc/s}$. The other components are only troublesome if their frequencies, given by (4), happen to be in the neighbourhood of f_i and if, moreover, their amplitudes are fairly large. Thanks to a suitable choice of the fixed frequencies (200.0 and 200.3 Mc/s) and of the variable frequency f_v , parasitic intermediate frequencies occur only for rather high values of the coefficients in (4); in other words: only certain modulation products of high orders have frequencies that can be troublesome. Now a high order means a small amplitude, so the trouble experienced is not very great.

Moreover, a substantial reduction in interference is obtained by arranging each of the oscillators O_1 and O_2 in push-pull at the input and in parallel at the output side (see fig. 6). In this way m , n , p and q are limited to odd numbers.

A further help is the aural observation of balance, the ear being able to distinguish the wanted beat note from parasitic ones.

The result is that over the whole range of measuring frequencies only at a few isolated values of f_m some interference is experienced. The unwanted signals considered here do not influence the measuring result, in contradistinction to those discussed in preceding paragraphs.

Summary. Measurement of complex voltage ratios is necessary to obtain the Nyquist curve of feedback amplifiers or other networks. In order to investigate the stability of the amplifier, the frequency range of the measurements must be extended far beyond the highest frequency for which the amplifier is intended. In the present instrument, this range is from 1 to 100 Mc/s.

Two voltages with a fixed intermediate frequency $f_i = 0.3 \text{ Mc/s}$ are derived from the input and output voltages of the network under test by means of a system of frequency conversion. The I.F. voltages have the same complex ratio as the H.F. input and output voltages, whose frequency is, of course, the variable measuring frequency. In a balancing system, one of the I.F. voltages is changed in amplitude and phase — by amounts readable from dials — until it cancels the other. Balance is indicated by the vanishing of a beat note from a loudspeaker. The accuracy is better than 0.2 dB in modulus and better than 2° in phase angle.

The variable measuring frequency f_m is obtained as the difference between a frequency f_v variable from 201.3 to 300.3 Mc/s and the frequency 200.3 Mc/s derived from a crystal oscillator. In a similar way, an auxiliary frequency f_a is obtained as the difference between f_v and the frequency 200.0 Mc/s derived from a second crystal oscillator. So by merely varying f_v , the frequencies f_m and f_a are varied simultaneously, while the difference $f_a - f_m$ is kept constant at 0.3 Mc/s. Voltages with frequency f_a are mixed with the input and output voltages (frequency f_m) of the network under test for producing the I.F. voltages to be compared.

Of the various components described, special mention should be made of the phase balancing device, from the dial of which the phase angle to be determined can be read.

An Appendix deals with the suppression of stray effects that would falsify the measurements.

ABSTRACTS OF RECENT SCIENTIFIC PUBLICATIONS OF THE N.V. PHILIPS' GLOEILAMPENFABRIEKEN

Reprints of these papers not marked with an asterisk * can be obtained free of charge upon application to the Administration of the Research Laboratory, Kastanjelaan, Eindhoven, Netherlands.

1993: J. J. Zaalberg van Zelst: Over versterkers met weinig veranderende versterking (T. Ned. Radiogenootschap **16**, 117-135, 1951, No. 3). (On amplifiers with almost constant gain; in Dutch.)

This article contains a survey of methods providing a reduction of the variation in gain of amplifiers. The methods using at least some constant network elements are divided into two groups. In those of the first group the influence of the actual change of the constants of the valves is eliminated by corrections of the input or output voltages, in those of the second group the actual change is reduced by regulating voltages derived from an auxiliary signal.

It is also shown to be possible to construct an amplifier having small variations in gain when elements are used which are not constant but have a limited variation. The fundamental limits of this procedure are discussed, regarding oscillators to be selective amplifiers of noise with positive feedback. See Philips techn. Rev. **9**, 25-32 and 309-315, 1947.

1994: J. A. Kok: On electrostatic plasma oscillations in metals (Physica **17**, 543-547, 1951, No. 5).

In this article an attempt is made to apply to metals the equations of the electrostatic plasma oscillations and of ions in electrical discharges in gases. It is pointed out that for electrons in metals the Fermi-Dirac distribution law has to be used and not the Maxwell statistics. The frequencies of the electrostatic ion oscillations have an upper limit of the same order of magnitude as the Debye maximum frequency.

R 165: H. B. G. Casimir: On the theory of electromagnetic waves in resonant cavities (Philips Res. Rep. **6**, 162-182, 1951, No. 3).

In these lectures (Madrid 1949) a survey is given of the theory of standing electromagnetic waves in resonant cavities. The formal analogy between the modes of vibration of a cavity, the modes of vibration of a network of discrete elements, and the vibration of a simple *LC* circuit is emphasized. Special attention is given to the theory of perturbations; this theory is then applied to a number of examples. These include the determination of the

high-frequency properties of magnetic materials by means of cavities into which small spheres of the material are introduced, and the coupling of two identical cavities by a small hole in a dividing wall. In the last section some remarks are made about the zero-point energy of empty space.

R 166: J. L. Meijering: Segregation in regular ternary solutions, II (Philips Res. Rep. **6**, 183-210, 1951, No. 3).

A straightforward method for numerical calculation of tie-lines is given and applied for several combinations of the parameters. When a tie-line has been calculated, the equation furnishes an infinite set of parameter combinations where the same tie-line appears. The initial directions of the binodal curves are given; the widening or narrowing of a binary miscibility gap by a small addition is governed by the difference in affinity of the added substance for the components of the binary system. In certain systems there is a pseudo-binary section. When *a*, *b* and *c*, the coefficients occurring in the thermodynamic potential, are positive, three-phase equilibria appear and the stability of the computed phase diagram must then be checked by means of the spinodal curve. A four-phase transformation of the eutectic type appears when *a*, *b* and *c* are about equally positive. Solubility curves of a pure solid component and their interference with a miscibility gap are also treated. Some remarks are made on multicomponent systems.

R 167: G. Diemer: Microwave diode conductance in the exponential region of the characteristic (Philips Res. Rep. **6**, 211-223, 1951, No. 3).

A transit-time theory is expounded for the conductance of a diode in the exponential region of its characteristic. A linear retarding field is assumed, and mutual electron interaction is ignored. For diodes with short distance between cathode and anode the value of this conductance in the voltage range $-2V < V_a < -1V$ may considerably exceed that of the total-emission conductance even in the microwave band. Application of the theoretical results to earlier measurements on "short-distance" diodes disposes of part of the former discrepancy between theory and experiment.

- R 168:** J. B. de Boer: Visibility of approach and runway lights (Philips Res. Rep. 6, 224-239 1951, No. 3).

In this paper the physiological data governing the visibility of steady lights are surveyed. For circular sources of light extensive information can be obtained from the results of observations published by several investigators. The influence of the shape of the sources and that of neighbouring light sources has been empirically studied for rectangular sources and for sources arranged in rows. Further, a brief account is given of what is known regarding the influence of the colour of the light. All these influences can be allowed for by applying correction factors. To this end, "size", "shape", "row" and "colour" factors have been introduced. The threshold values found in the laboratory have to be multiplied by a safety factor in order to get data suitable for calculating the luminous intensities required in order that a pilot in actual flight will be able to see the lights.

- R 169:** J. B. de Boer: Calculations of the light distribution of approach and runway lights (Philips Res. Rep. 6, 241-250, 1951, No. 4).

The relation between daylight-visibility in a foggy atmosphere and the transmission of light through fog is treated briefly and qualitatively in so far as data are needed for calculating the required luminous intensity of approach and runway lights. Fundamental physiological information on the visibility of lights through fog, required for the same calculation, has been taken from an earlier paper in these Reports. A method of calculation is described which allows of the luminous intensity of approach and runway lights and its spatial distribution being determined in a simple way (by means of two graphs).

- R 170:** G. J. Fortuin: Visual power and visibility (Philips Res. Rep. 6, 251-287, 1951, No. 4).

Since several decennia the visual acuity (the reciprocal value of the angular size of the smallest perceptible object) has been the most usual standard of visual capacities, although it was known that its value depends on the examining conditions (the contrast of the test objects, the exposure time, the field brightness, etc.). With due alterations of details the same applies to other standards of visual capacities, such as contrast sensitivity and speed of vision. Nevertheless, the capacity of obtaining information about the electromagnetic behaviour of one's sur-

roundings is a property exclusive to the observer and, therefore, independent of external conditions. In this paper a quantitative definition is given of this capacity, which is called the "visual power". This definition is based on 9120 determinations, so that generally the visual power is indeed independent of the experimental conditions. Subjects, 228 in total, were school children, applicants for employment and employees.

The visual power decreases with increasing age and this decline is already present at ages under twenty years. A further consideration of the results revealed the occurrence of some different visual types, one of them being due to the presence of opacities in the optical media of the eye.

- R 171:** K. S. Knol: Determination of the electron temperature in gas discharges by noise measurements (Philips Res. Rep. 6, 288-302, 1951, No. 4).

The use of an electric discharge in a gas as a microwave noise source has been studied. It appears that the noise power available is determined by the electron temperature of the discharge. Certain precautions have to be taken in order to obtain a relatively loss-free matching of the discharge conductance to the waveguide. The electron temperatures of He, A and X are measured as functions of the gas pressure and the direct current. A comparison of these measurements is made with a theoretical formula for the electron temperature as a function of the product of the gas pressure and the radius of the discharge tube. The agreement between theory and experiment is satisfactory. The values of the electron temperature determined in the same discharge tube by noise measurements and by probe measurements are equal within the limits of accuracy. From semi-theoretical arguments a relation is derived between the electron temperature in a gas discharge and the longest resonant wavelength of that gas.

- R 172:** J. M. Luttinger *): Wave propagation in one-dimensional structures (Philips Res. Rep. 6, 303-310, 1951, No. 4).

A conjecture of Saxon and Hutner (see No. R 102 of these abstracts) on the forbidden energy levels of any substitutional alloy of a certain one-dimensional crystal model is proved. Analogous results are derived for wave transmission down a line loaded with two-terminals.

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